

Final Report
Programmable Flight Controller
Prepared for Reiland Systems
Internal Supervisor: Dr. Jason Gu
External Supervisor: Dr. Jason Rhinelander

Brendon Camm Lucas Doucette Dylan Humber
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Department of Electrical
and Computer Engineering
Dalhousie University
P.O. Box 1000
Halifax, Nova Scotia
B3J 1B6

March 26, 2017

Dr Jason Rhinelander
Reiland Systems Ltd.
PLACEHOLDER ADDRESS
Dartmouth, NS
POSTAL CODE
CC: Dr. Jason Gu
Dr José Gonzalez-Cueto
ECE Support Secretary

Dear Dr. Rhinelander:

Attached is Group 2s senior design interim report titled Programmable Flight Controller, written in fulfillment of the requirements of the Faculty of Engineering ECED 4901 Senior Design course. The report outlines the specifics of each portion of the project encounters throughout the 2016/2017 academic year.

The intention of this project is to develop a completely programmable flight controller for use on a quad-rotor drone. The controller and sensors will be implemented using an Arduino Uno Microcontroller and Raspberry Pi 3 computer. A graphical user interface was also developed to display information about the controller and sensors. The sections enclosed in the attached report discusses the simulation, implementation and testing of the controller as well as the design and testing of the graphical user interface. In addition, this report outlines the management side of the project including the Gantt Chart showing the time-lines, task division and each individual group members responsibilities. The report concludes with sections highlighting some of the challenges that were encountered over the course of the project including a new legislation regarding recreational drone usage introduced by the federal government in March of 2017 which severely disrupted our planned flight testing following this section will be recommended future improvements.

Please contact the groups nominated project manager, Dylan Humber (at dylan.humber@gmail.com) should you have any questions about the report.

Best Regards,

Dylan Humber

Brendon Camm

Lucas Doucette

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Abstract

The following report summarizes the progress made throughout the Quad Rotor Drone Programmable Flight Controller project and the future recommendations based upon project findings. The goal of the project is to design a programmable quadcopter flight controller that will have the capability of responding to live control inputs and react appropriately to disturbances present. The objective of this report is to summarize the deliverables set forth for the project and to present findings, results and testing procedures. The report also outlines the design process of the project. The Quad Rotor Flight Controller project has three major components; flight and stabilizing simulations, implementation of software, and a GUI interface.

Authorship

- Abstract - Lucas Doucette
- Letter of Transmittal - Brendon Camm
- Simulations - Dylan Humber
- GUI - Brendon Camm
- Physical Implementation - Lucas Doucette
- Conclusions - Dylan Humber
- Future Recommendations - Group
- References - Group
- Appendices - Group
- Instruction Manual Abstract - Lucas Doucette
- Instruction Manual Procedure- Lucas Doucette
- Instruction Manual Simulations- Dylan Humber
- Instruction Manual Raspberry Pi- Dylan Humber
- Instruction Manual Arduino - Lucas Doucette
- Instruction Manual GUI - Brendon Camm

1 List of Acronyms

1. BLDC - Brushless Direct Current
2. DOF - Degrees of Freedom
3. FOV - Field of View
4. GUI - Graphical User Interface
5. HID - Human Interface Device
6. IMU - Inertial Measurement Unit
7. PD - Proportional Derivative
8. PI - Proportional Integral
9. PID - Proportional Integral Derivative
10. POC - Proof of Concept
11. PWM - Pulse Width Modulation
12. RF - Radio Frequency
13. RPi - Raspberry Pi
14. USB - Universal Serial Bus

2 Introduction

2.1 Background and Significance

Machine learning is defined as the science of getting computers to act without being explicitly asked. This is achieved by the development of computer programs that can teach themselves to grow and change when exposed to different sets of data. There are two traditional types of machine learning algorithms: Batch learning algorithms and on-line machine learning algorithms. Batch learning algorithms require a set of predefined training data that is shaped over the period of time to train the model that the algorithm is running on. On-line learning uses an initial guess model that forms co-variates from that initial guess then passes them through the algorithm to form an evolved model a new set of covariates are formed from the evolved model and then fed back to make a new prediction. The loop

runs continuously so that the evolved model is constantly growing and learning to adapt to certain situations. Dr. Rhinelander's research is concerned with on-line machine learning algorithms therefore the drone we are developing will be configured to adapt with these algorithms.

Quad rotor drones have been on the rise in popularity in the last several years due to their simplistic mechanical design and many practical uses. The application of these drones vary from a hobbyist flying around their neighbourhood to military personnel carrying out high risk missions. A video recording device of some sort is generally attached to the drone and the video feed is relayed to a base station for the operator to gain a field of view (FOV) of an area of interest. Having the capability to have a continuous video feed allows the drone to be used for many practical applications including but not limited to: Traffic condition monitoring and surveillance missions. While these drones are very sophisticated and advanced devices they are missing one aspect that is very important to further Dr. Rhinelander's research: They are not totally configurable.

As mentioned, Dr. Rhinelander's research is concerned with on-line machine learning algorithms and without a platform that is completely configurable his research would be limited. Before the machine learning algorithms are implemented onto the drone it must first be able to be controlled. This is where we come in, we have been tasked by Dr. Rhinelander to develop a flight controller that receives control inputs over Wi-Fi. Having a completely open source flight controller will allow for the addition of the machine learning algorithms to the flight controller software so that the drone can learn to partially, and eventually fully fly on its own and make intelligent decisions.

2.2 Overall Objective

The main objective of the project is to develop a programmable flight controller that responds appropriately to control inputs and disturbances. The flight controller will receive control inputs over Wi-Fi from a base station. The base station can be any device that is Wi-Fi enabled and has the appropriate software installed. The software on the base station will be a graphical user interface (GUI) that allows the user to send control inputs to the drone and view statistics of the drone during operation.

2.3 Simulations

The simulations will allow us to gain an understanding of how the controller will respond to specific inputs. The simulation can then be tuned to test various PID constants for performance. We will be simulating both the flight dynamics and

controller using MATLAB and Simulink exclusively.

Additionally, the simulation will be able to take input from both predefined control sequences and HID on the operating system. As real time input from a HID is desired for the simulation, real-time rendering in 3D will be attempted.

2.4 Physical Implementation

The physical implementation of the drone software and hardware requires a communication channel between a control input, a base station host, a wireless communication receiving unit, and a host for the controlling system. The objective of the physical implementation is to provide the software and hardware design required to successfully implement a quad rotor drone flight controller. It is desired to have a controller that is capable of sensing disturbances in flight and stabilizing the system based upon the measured disturbances.

The objectives of the physical implementation for the project begin with successfully creating a Wi-Fi communication channel between a controller input and a wireless device placed on the drone hardware. The drone is to have flight sensing capabilities, interfaced with both the on board wireless device and a grounded controlling station. The flight sensing is to include yaw, pitch, roll and altitude measurements with a polling rate sufficient for real time control of the drone. The flight sensing is to be combined with a set point from the wirelessly transmitted control input by a PI or PID loop to control the flight of the drone with stabilizing features. The code written for the control input, communication interface, and finally the controller is to be well documented to ensure ease of use and simplicity for updating and modifying after handing over the final product.

2.5 Graphical User Interface

The Graphical User Interface (GUI) requires a network connection between the base station host it lives on and the Raspberry Pi 3 to receive the serialized dictionaries containing sensor data and controller information. The objective of the GUI is to provide the user with a medium to access information regarding the current flight, such as, the altitude at which the drone has flown or how the physical controller is configured. It is desired to have a real time plot of the altitude based on the sensor information and the ability to initialize the physical controller.

The objectives for the GUI for the project start with selecting an appropriate development framework that will function across Windows, Mac OS and Unix environments. The GUI is to have the ability to initialize the communications between the base station host and Raspberry Pi 3 to allow for the control inputs to be sent using the base station host as well as receiving the data that is to

be displayed on the GUI. The GUI is to be intuitive to avoid any unnecessary confusion with the end user. The code written and any other software used for the GUI will be provided and well documented to ensure that in event that the end user would like to modify anything after receiving the final product, this can be done effortlessly.

3 Methods

3.1 Simulations

In order to begin pursuing the simulation, problem areas were first identified. This is to say, the investigation or creation of blocks that we had no experience with. The PID and other control blocks used in the simulation we were already accustomed to. Other blocks such as addition, gain, (de)multiplexers, and other common blocks we were also familiar with. The solutions to these problem areas, as well as the overall design of the simulation is discussed in section 4. The problem areas that we identified were as follows:

- HID Input
- Physical simulation
- Real-time rendering

The investigation into these issues would first begin by searching for existing blocks or packages within SimuLink. In the absence of already existing solutions, useful packages would be identified. Any packages or blocks that could be used as tools to build the desired effect. Subsequently, the amount of effort to build the result into the simulation using these packages would then be evaluated. However, in the progression of the simulation, the majority of the tools (as discussed in section 4) were easily used to implement the problem areas.

3.2 Physical Implementation

The physical implementation of the system began with determining a method to interface a controller input with a base station host. To do this, research of available python libraries was performed. It was determined quickly that the most effective route would be to use Python's Pygame library which analyses a bluetooth or usb connected device and determines the types of control inputs applicable for the device. Initially, a PS4 bluetooth connected controller was successfully utilized, receiving all axis and button inputs through the Python interface.

The next challenge of the physical implementation was to determine the best method of Wi-Fi communication. It was determined that Python's socket library would be best suited, and a Raspberry Pi 3 with a Wi-Fi module available would act as the server in the server, client architecture. A preliminary communication server client script set was written and tested successfully between the base station laptop and the Raspberry Pi server host.

For the controller host, two possible solutions were considered. Utilizing an Arduino micro-controller as a permanent host of the control loop, communicating with the Raspberry Pi to receive control input data or using the Raspberry Pi for both communication and the controller. Using Arduino would provide a dedicated control loop and an intuitive interface to prototype with. The Raspberry Pi is capable of running the control loop, but issues with regards to a real time operating system were anticipated. Using an Arduino would require more mounting space on the drone as well as another communication channel between the RPi and Arduino to troubleshoot. Many other controllers could have been considered but both RPi and Arduino are owned by group members.

The controller required input from a 10 degree of freedom inertial measurement unit to calculate yaw, pitch, roll and altitude to poll and compare to the control set points. Eventually, alternative methods of calculating altitude were considered and discussed. The methods included infra-red distance sensing, ultrasonic sensing, multiple barometers coupled with Kalman filters, or a barometer accelerometer coupling. PI and PID loops were researched to be implemented on the controller. Several additional filtering techniques were considered for altitude measurement, including moving average filtering, averaging filtering and Kalman filtering with a feedback loop for comparison.

Communications between the RPi and the Arduino were researched, using the interface to interface bus or the serial communication channel were both considered. The data was required to be transmitted as single bytes, thus an algorithm to convert received bytes into floating point values needed research and development.

From a technical background perspective, research regarding the Python language and Python's available libraries was required. Server to client interfacing is also required technical background. Previous knowledge of the Python language assisted in directing the research and development flow throughout the project. PI and PID control loop knowledge was required and research time was used to learn filtering processes, Arduino library development, miscellaneous communication algorithms and utilization of the Adafruit 10 DOF IMU.

3.3 Graphical User Interface

3.3.1 Framework Selection

There is a multitude of frameworks available for graphical user interface development so in order to narrow down the choices the following restrictions were placed:

- Must function on Windows, Mac OS and UNIX environments
- Have the ability to display live plots
- Be compatible with the physical controller initialization software
- Have well documented libraries for ease of development

With these restrictions placed and further research into various frameworks the selections narrowed down to Qt and PyQt5. Each of these use the Qt framework which is regarded as a reliable, cross-platform GUI development software with extremely well documented libraries which met the major requirements. Although both Qt and PyQt5 use the same framework there are a few key differences.

The most notable difference at first glance is that the two use different languages, Qt uses C++ where PyQt5 uses Python but the biggest difference is in the design suites. When developing using Qt you're able to use the QtCreator design suite which allows the user to design the look of the GUI using click and drag widgets, code the functionality of the widgets then simply compile all within the design suite. When using PyQt5 there isn't a complete design suite, instead the user must design the user interface using QtDesigner and then import the GUI file into the Python script, from here the widgets are coded is relatively the same other than the obvious differences between C++ and Python. To finalize the decision on which framework to use two basic GUI's with the same functionality were developed using Qt and then PyQt5. From a technical background perspective, research regarding Python and C++ languages and the available libraries for each was required as well as research into the capabilities of both Qt and PyQt5 development frameworks.

3.3.2 Features

Many different features were considered when initially designing the graphical user interface such as:

- Display Live Plots
- Initialize Manual Control of the Drone

- Manipulate and display PI and PID Parameters
- Display Sensor Status
- Display Flight Time
- Initialize communications between base station host and Raspberry Pi 3

Each of these features have pros but upon further research on how each individual feature could be implemented highlighted that some may be out of the scope of this project. It was decided that regardless of the difficulty of implementation that our GUI would at least contain the ability to have live plots, initialize the physical controller and initialize the communications between the base station host and Raspberry Pi 3 therefore further research was put into these. From a technical background perspective the research done required knowledge of the Qt and PyQt5 framework, networking knowledge and knowledge about basic PI and PID controllers.

3.3.3 GUI Layout

The layout of a GUI can make or break the end users experience, a clunky non-intuitive GUI will undoubtedly cause the end user an unneeded headache. For this reason, a prototype of a graphical user interface that included some of the features mentioned above was developed and sent to our client to get an idea of what he would be comfortable with, this prototype was then optimized based on his comments. From a technical background perspective designing the two prototypes requires knowledge on how to develop using QtDesigner as well as basic GUI layout techniques.

3.3.4 Live Plotting

When thinking about how to plot the live sensor data two libraries were considered these are, matplotlib and pyqtgraph. Matplotlib is a favorite when it comes to plotting data with Python where pyqtgraph is a plotting library specifically developed for use on PyQt. Each of these libraries were used to create plots on the GUI and then the performance was examined. The performance factors that were considered were: latency to plot when data is received and accuracy of the plotted data. Research into both of these libraries and how they can be integrated into the user interface was performed.

4 Proposed Solutions

4.1 Simulations

For the control design, four separate controllers will be used. A PID controller will be used to control the altitude of the quad-rotor drone. Pitch, roll, and yaw will each be controlled respectively by a separate PI controller. These controllers will be first tested and tuned using test inputs. The physical aspect of the simulation will be defined by a SimScape MultiBody model. Once this rudimentary model is verified, the simulation will be developed into taking real-time signals from a HID and rendering the flight of the quad-rotor drone in response to user input.

4.1.1 Simulation Design

The overall architecture of the proposed design can be seen in Figure 4.1.1. The entire system is broken down into six subsystems. Their specifications are discussed below. The layout of each subsystem and the overall SimuLink simulation layout may be found in Appendix A.

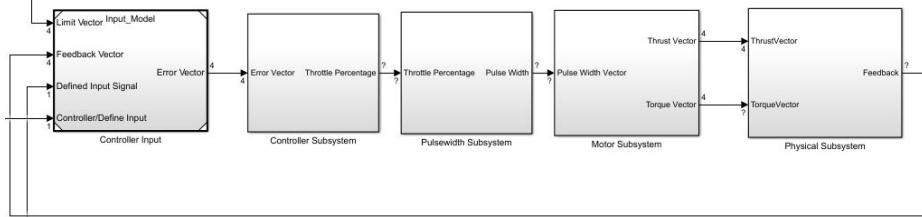


Figure 1: Proposed Simulation Architecture

1. **Input Block:** This block handles the HID input and pre-configured test signals. As well as the specifications of limit/scalar values of the input signals. As the limits will be scalar values, control signal input should be restricted between -1 and 1 .
2. **Feedback Block:** This block receives the contents specified from the input block as well as the current orientation of the quad-rotor drone in the simulation. It combines all of these to output an error signal for the pitch, roll, yaw, and altitude controllers.
3. **Controller Block:** This block houses the four controllers. The output of these controllers is normalized to a throttle percentage.

4. **Pulsewidth Subsystem:** This block takes the throttle percentage and transform it to a value in microseconds that can be used to define the pulsewidth output of the microcontroller. Physically, this PWM signal controls the ESCs.
5. **Motor Characterization:** This block contains motor thrust data corresponding to characterization tests performed in the first semester. Functionally this block contains a look up table that relates pulsewidth to thrust and torque for each motor. The torque value is an approximation based on the value of thrust from the motor.
6. **Physical Subsystem:** This block contains the physical subsystem built in SimScape Multibody. This library allows for the system to be built quickly and easily, as well as providing a (although simple) 3D rendering model.
7. **3D Rendering:** This subsystem will handle the real-time rendering of the simulation for flying with input from the HID.

4.2 Physical Implementation

The proposed solution incorporates the following components for the physical system architecture.

- Joystick Controller
- Base Station Laptop
- Raspberry Pi 3 Computer
- Arduino Micro-Controller
- 10 Degree of Freedom Inertial Measurement Unit
- Raspberry Pi Camera Module (Future)

The system architecture is implemented as depicted in the block diagram shown in Figure 2.

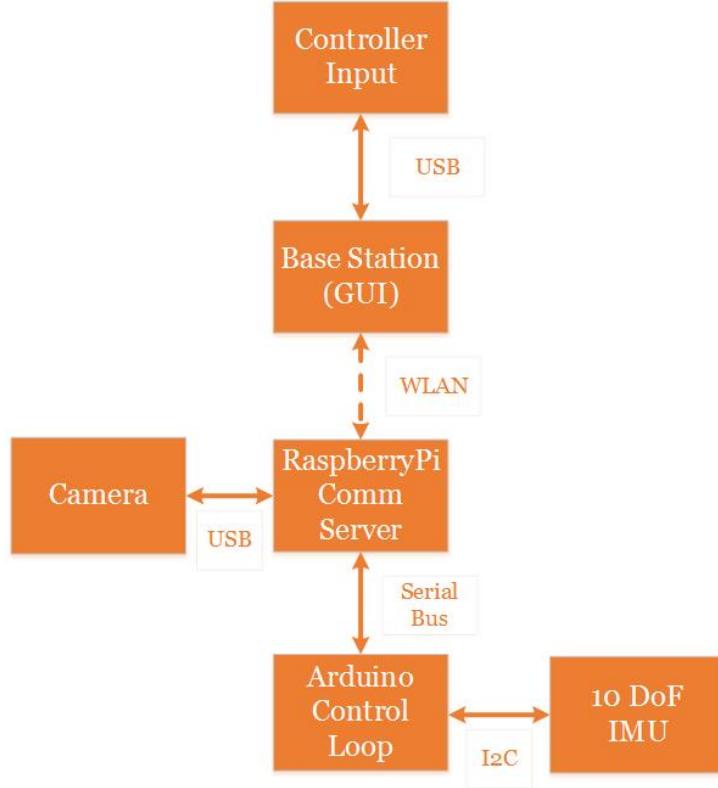


Figure 2: System Architecture

A joystick controller was used as the control input for its non-spring loaded throttle control. The drone requires an altitude set point from the control input, a spring loaded control input would make the implementation of a constant set point difficult. The base station laptop hosts the GUI and the communication channel software between the USB connected joystick control input and the Raspberry Pi Wi-Fi connection. The Python scripts that enable the communication channels use the sockets library for a server, client Wi-Fi channel and pygame library to acquire control set points from the joystick controller. The inputs from the controller are converted from floats to sets of four bytes for transmission.

The Raspberry Pi is used solely as a communication channel between the base station and the Arduino control loop. The RPi is the server while the base station is considered the client in the connection. The Raspberry Pi relays the received bytes to the Arduino control loop using a serial communication channel.

The Arduino control loop is used to host the drone function library and main script required for drone flight. The Arduino control loop outline is shown in Figure

3. The gain values for the PID loop are to be determined through simulations. The Arduino initializes all sensors, motors, and communications. The loop then gathers data from the inertial measurement unit and the serial connection to the Raspberry Pi, compares the data and performs PID loops, finally outputting the results to the ESCs.

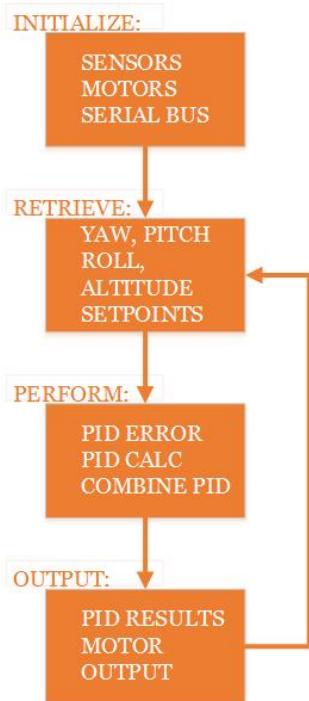


Figure 3: Arduino Control Loop

Yaw, pitch, roll and altitude are calculated using the accelerometer, gyroscope, magnetometer, barometric pressure sensor and temperature sensor available on the inertial measurement unit. The altitude measurement is completed using the barometric pressure sensor and temperature sensor. The equation to calculate altitude is given as:

$$h = \frac{(\frac{P_0}{P})^{1/5.257} - 1}{0.0065} * (T + 273.15)$$

h = Difference between Starting Height and Current Height

P_0 = Initial Pressure at Starting Height

P = Current Pressure

T = Current Temperature

The barometric pressure sensor calculation was found to be highly susceptible to noise, several filtering techniques were attempted and a Kalman filter with a feedback comparison is currently in use. This filtering technique is subject to change. For the initial 2.5m of altitude, the drone utilizes an ultrasonic sensor to measure altitude. All written scripts for the Arduino, Raspberry Pi and the base station communication channel can be found in Appendix B.

The hardware build of the drone requires mounting the Arduino and Raspberry Pi on the drone, connecting the 10 DOF IMU to the Arduino through an I2C connection, ESC connections through the available PWM pins on the Arduino, and a serial connection to the Raspberry Pi. The ESCs are to be powered by a Li-Po battery through a power distribution board. The power distribution board will also provide power supply to the Raspberry Pi, supplying power to the Arduino through the serial USB connection.

The final physical implementation is shown in Figure 4.

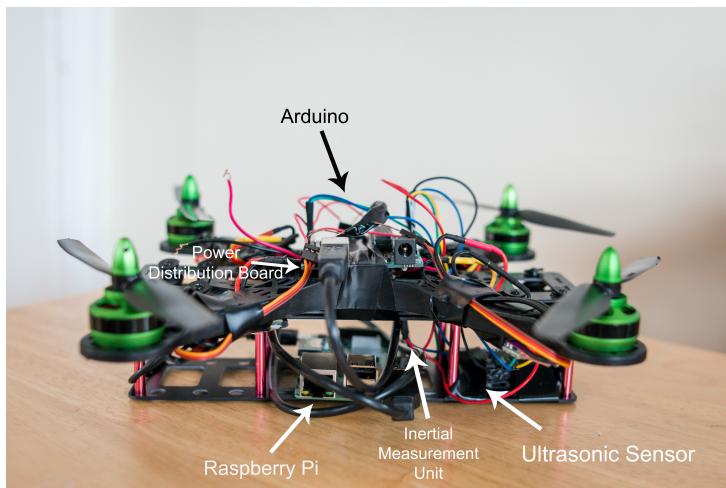


Figure 4: Final Drone Build, Photo Credit: Alicia Hoyt Photography

The PID loop implementation utilizes the Forward Euler equation. The scripted solution to the PID loop can be seen in Appendix B and the mathematical breakdown is as follows. Note, the forward Euler equation is manipulated algebraically to obtain the numerator and denominator coefficients.

$$ForwardEuler = k_P + k_I * T_s * \frac{1}{z - 1} + k_D * \frac{N}{1 + N * T_s * \frac{1}{z-1}}$$

$$C(z) = \frac{U(z)}{E(z)} = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2}}{a_0 + a_1 z^{-1} + a_2 z^{-2}}$$

$$\begin{aligned}b_0 &= k_P(1 - N * T_s) + k_I * T_s(N * T_s - 1) + k_D * N \\b_1 &= k_P(N * T_s - 2) + k_I * T_s + 2 * k_D * N \\b_2 &= k_P + k_D * N \\a_0 &= 1 - N * T_s \\a_1 &= N * T_s - 2 \\a_2 &= 1\end{aligned}$$

The implemented difference equation is denoted $u[k]$.

$$u[k] = -\frac{a_1}{a_0}u[k - 1] - \frac{a_2}{a_0}u[k - 2] + \frac{b_0}{a_0}e[k] + \frac{b_1}{a_0}e[k - 1] + \frac{b_2}{a_0}e[k - 2]$$

4.3 Graphical User Interface

4.3.1 Framework Selection

The basic GUI was to have the ability to call the joystick initialization script and manipulate the axis settings. Because the initialization script was written in Python it was very difficult and time consuming to do this using the C++ version of Qt compared to using PyQt5 where all that had to be done was import the script. Due to each of the scripts that the GUI needs to call are written using Python it was decided to carry on using PyQt5. On top of the ease of importing the scripts using PyQt5 it also allows us to use the vast amount of Python libraries that are available such as matplotlib and pyqtgraph and as discussed, these libraries will be used to plot the sensor data.

4.3.2 Features

As mentioned in section 3.3.2 how we could go about implementing each of the listed features was researched. Through this research it was revealed that some of the features we had originally considered were out of the scope of this project

because it would take too much time to implement for little benefit. For this reason the following features were removed from our consideration at this time, but they will be considered potential future improvements:

- Manipulate and Display PI and PID Parameters
- Display Sensor Status
- Display Flight Time

Therefore the key features that will be implemented into the GUI at this time are as follows:

- Initialize Manual Control of the Drone
- Initialize communications between Base Station Host and Raspberry Pi 3
- Display Live Plots

A detail explanation of how these features will be implemented into the GUI will be explained in sections 4.3.4-4.3.5.

4.3.3 GUI Layout

As explained in section 3.3.3 an initial GUI was developed and presented to our client this initial prototype can be viewed in the figures shown in Appendix D. As you can see from the figures in D the prototype presented to our client included most of the features we later deemed unnecessary therefore we could disregard these extra widgets. With the decision to not include the features and taking our clients comments into consideration a new GUI layout was developed. The new GUI layout includes all of the key features we have decided to implement and presents them in a clean and intuitive manner. This new layout was presented to each group member and a consensus was reached to carry on with development using this layout. The final GUI layout can be viewed in Figure 5 and Figure 6.

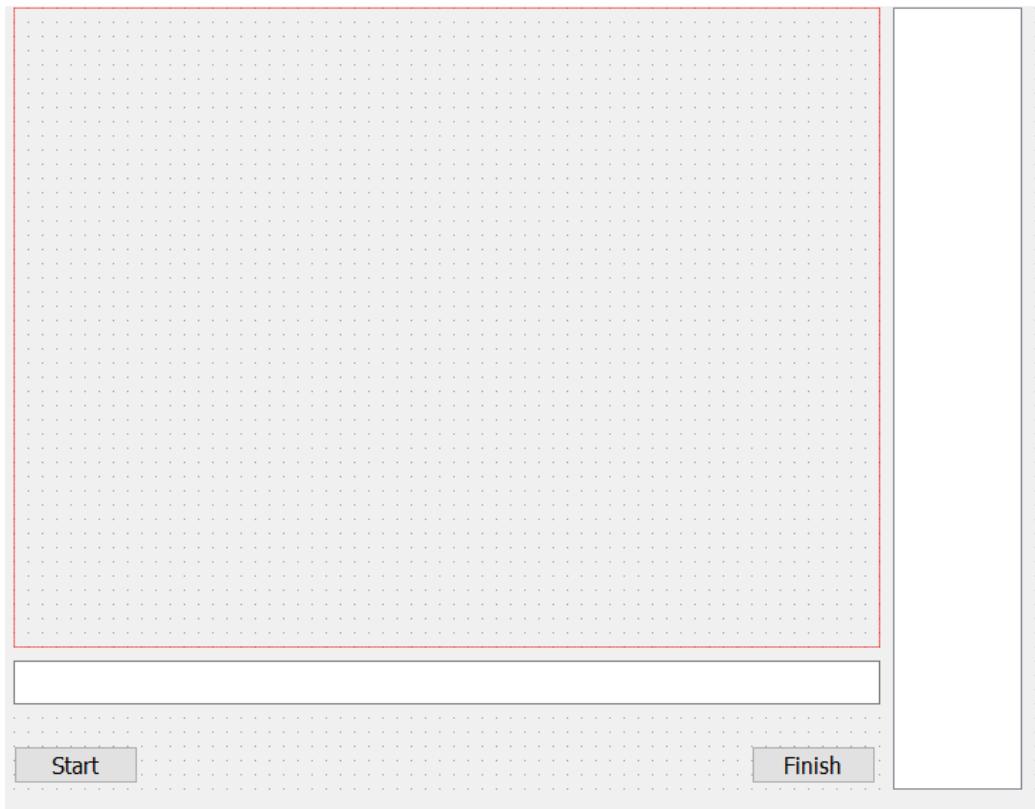


Figure 5: Final GUI Home Page

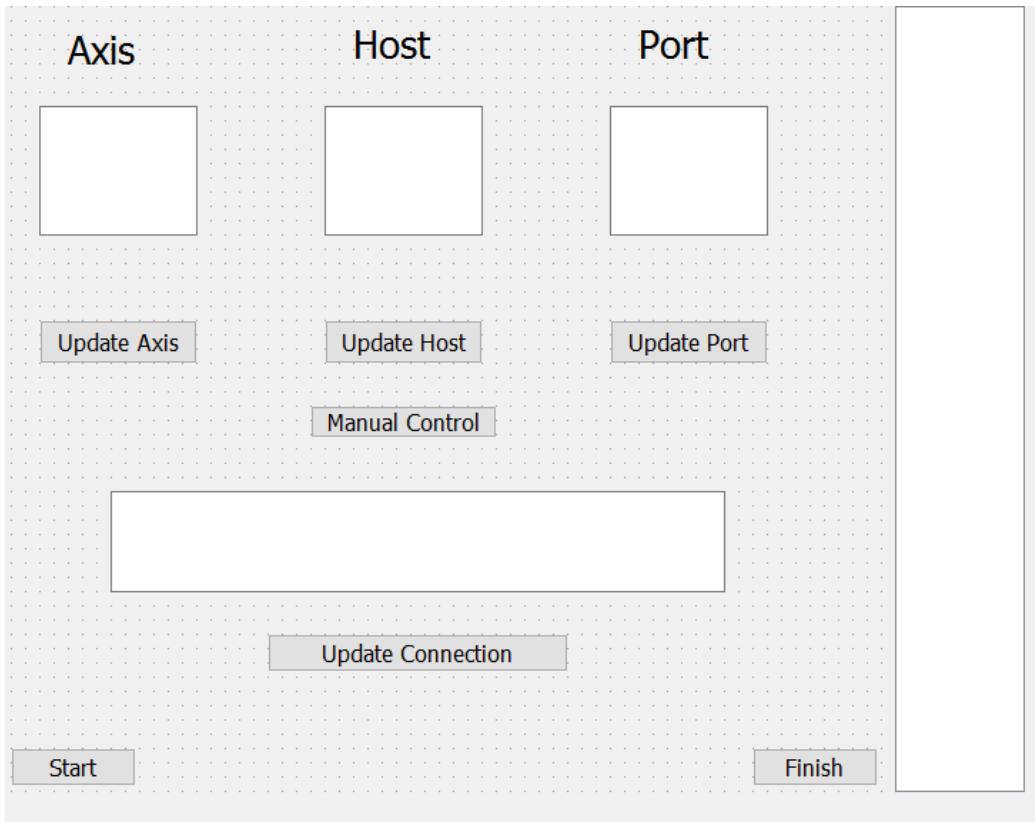


Figure 6: Final GUI Controller and Network Settings page

The red outlined box is the field that the live plot will populate when the GUI is compiled and the blank vertical rectangle is a list widget that will be populated with the names different pages of the GUI and will allow the user to access them by simply clicking on the name. An example of how the list widget will look can be viewed in Figure 7 and how the live plot will look can be viewed in section 4.3.5 Figure 10. An explanation of what purpose each of the other widgets and push buttons seen in Figures 5 and 6 will serve is described in the following sections.

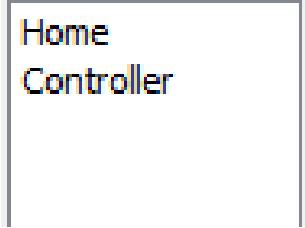


Figure 7: List Widget Example

4.3.4 Initializing Communications and Manual Control

In order for the GUI to receive sensor data or the controller to receive manual control inputs over WiFi a socket connection must be made. Instead of having to open and run the socket script on the client (base station host in our case) the Start button on the GUI calls the socket script and makes the connection to the socket. Once the Start button has been pressed the horizontal white fields found in Figures 5 and 6 will tell the users whether or not communications have been successfully made how this push is coded can be found in the connection() definition of the GUI code in Appendix D.1. When the GUI is initially compiled the white fields under Axis and Port seen in Figure 6 will be populated with the default values that are found in the Joystick script found in Appendix C.4 for the Axis values and the socket script for the Port value. The white field under Host will be populated with the name of the host computer's IP or name.

The Axis values will determine which direction the drone will go depending on which way the joystick is moved therefore if the user would prefer the drone move differently they have the option to change the joystick settings by hitting the "Update Axis" push button. How this push button is coded to achieve this functionality can be found in the updateAxis() method in the GUI code in Appendix D.1

In the event that the client script is altered and a new host and port number is to be used for the socket the "Update Connection" push button will allow the user to enter the new host and port values and then the connection to the new socket will be made. If only one value has changed the user can select either the "Update Host" or "Update Port" push buttons and then hit "Update Connection" and the new connection will be made. If either of these cases occur the horizontal white field found in Figure 6 will be populated letting the user know whether or not the values have been updated and the connection has been successfully established. How the Axis value, Host value, Port value and Connection Status will be displayed when the GUI is compiled and the Start button is pushed using the wrong port value can be viewed in Figure 8 and how the text field that pops up when you

click any of the push buttons mentioned looks can be viewed in Figure 9

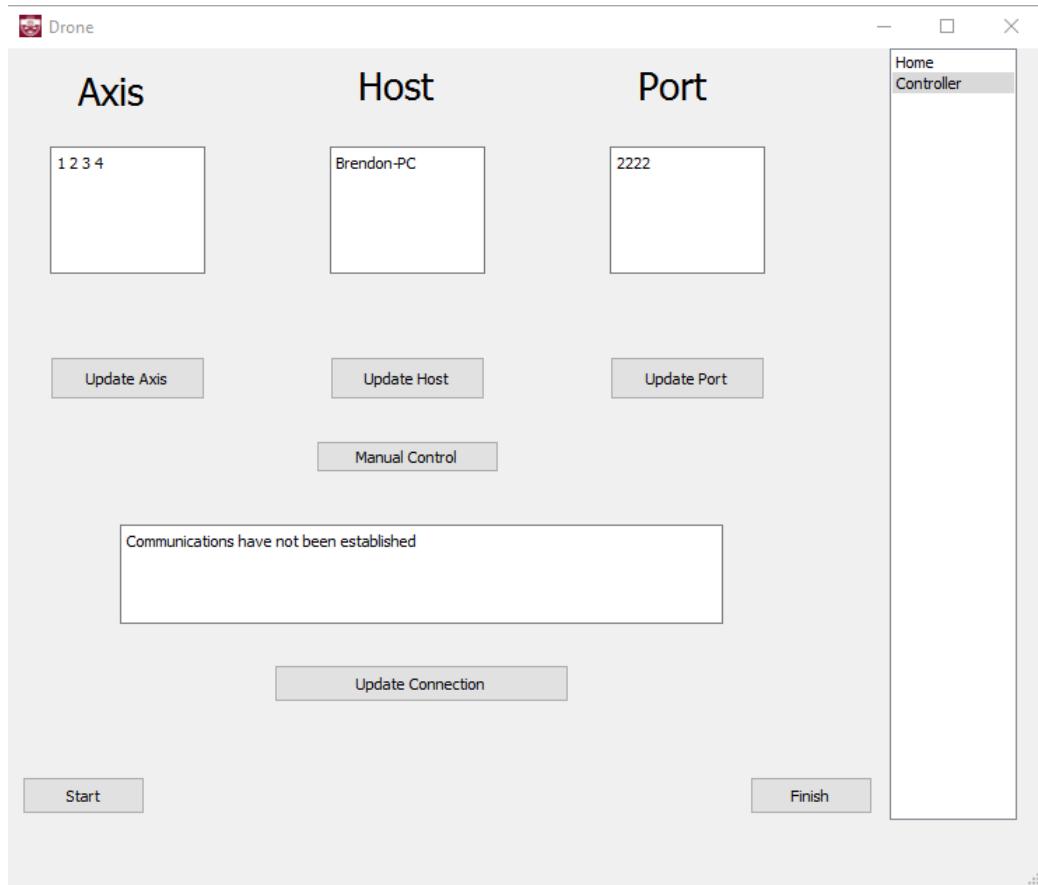


Figure 8: Compiled GUI with no active communications

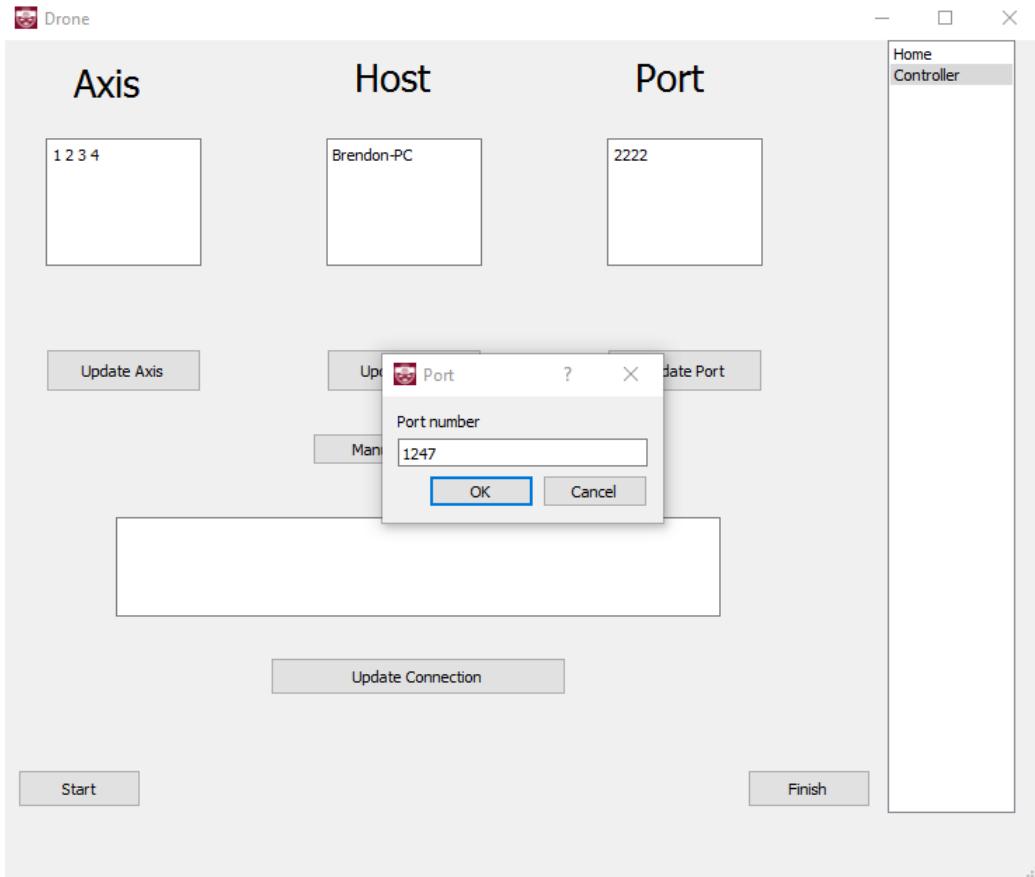


Figure 9: Pop up to input new values on GUI

As mentioned in section 2.1 Dr. Rhinelander has aspirations for the drone to partially or fully fly on it's own but in the event that something goes wrong there must be a way to manually control the drone. This is where the manual control button seen in Figure 6 comes into play. This push button calls the `listen()` definition of the Joystick initialization script found in Appendix C.4. This initializes the joystick settings and then makes the connection to the socket on the Raspberry Pi 3 this will allow for control inputs to be sent. In order for this to be performed the Server script found in C.3 must be running on the Raspberry Pi 3 and the port numbers must match. The code for how this push button performs it's functions can be found in the `connectController()` definition on the GUI code found in .

4.3.5 Live Plotting

As discussed in section 3.3.4 the libraries matplotlib and pyqtgraph were considered when trying to determine how to display the live plots on the GUI. When it came to just displayed a simple graph matplotlib integrated seemlessly into the GUI and looked clean. However, when it came time to update the plot a big problem was encountered this was whenever an update timer was connected to the plotting definition the instance of the plot window would repeat itself rather than pulling the data and updating the plot with the new values. Upon researching solutions to this issue it was discovered that when dealing with real time plots matplotlib has a real weakness but that pyqtgraph excels in this aspect. With these reasons combined it was decided that moving forward all live plotting will be performed using pyqtgraph.

When using pyqtgraph live plotting became much easier to achieve. To achieve live plotting three definitions are required to set up the initial plot, what to do when the plot updates and which direction to move the plot. These definitions can be found in the initplt(), update1() and move() definitions in the GUI code in Appendix D.1. Once these definitions are defined a QTimer must be connected to the move() definitions and an update interval will be defined the external dependancies and QTimer setup can be found under "Live Plotting" in the GUI code in APPENDIX. How the plot will look on the GUI can be seen in Figure 10.

On top of pyqtgraph being easier to implement it also includes some useful features. The user is able to click on the plot window and drag in any direction. For example, if the user was interested in data that occurred at time = 0 seconds but they were 100 seconds into data collection they would be able to click and drag back to the desired point to see the data of interest without disrupting data collection. If the user left clicks they are also to instantly obtain the maximum and minimum X and Y values, or in our case maximum time and amplitude values an example of the can be viewed in Figure 11

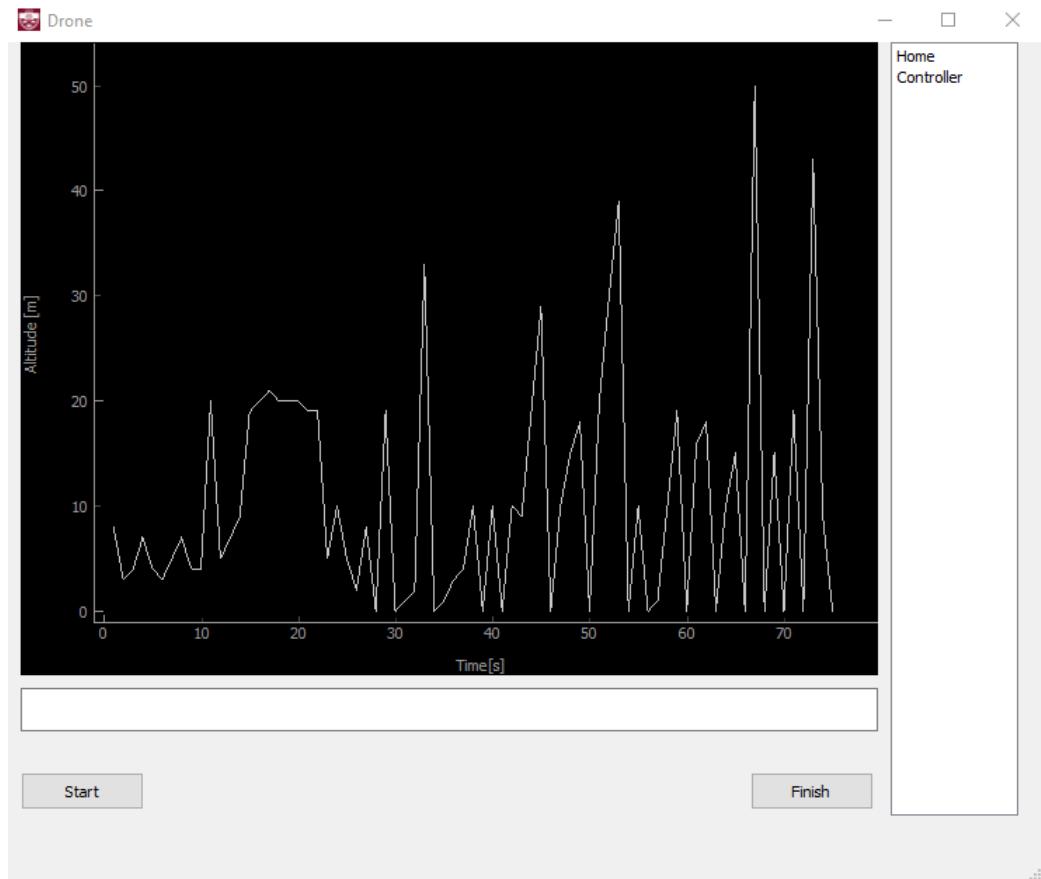


Figure 10: Live Plot

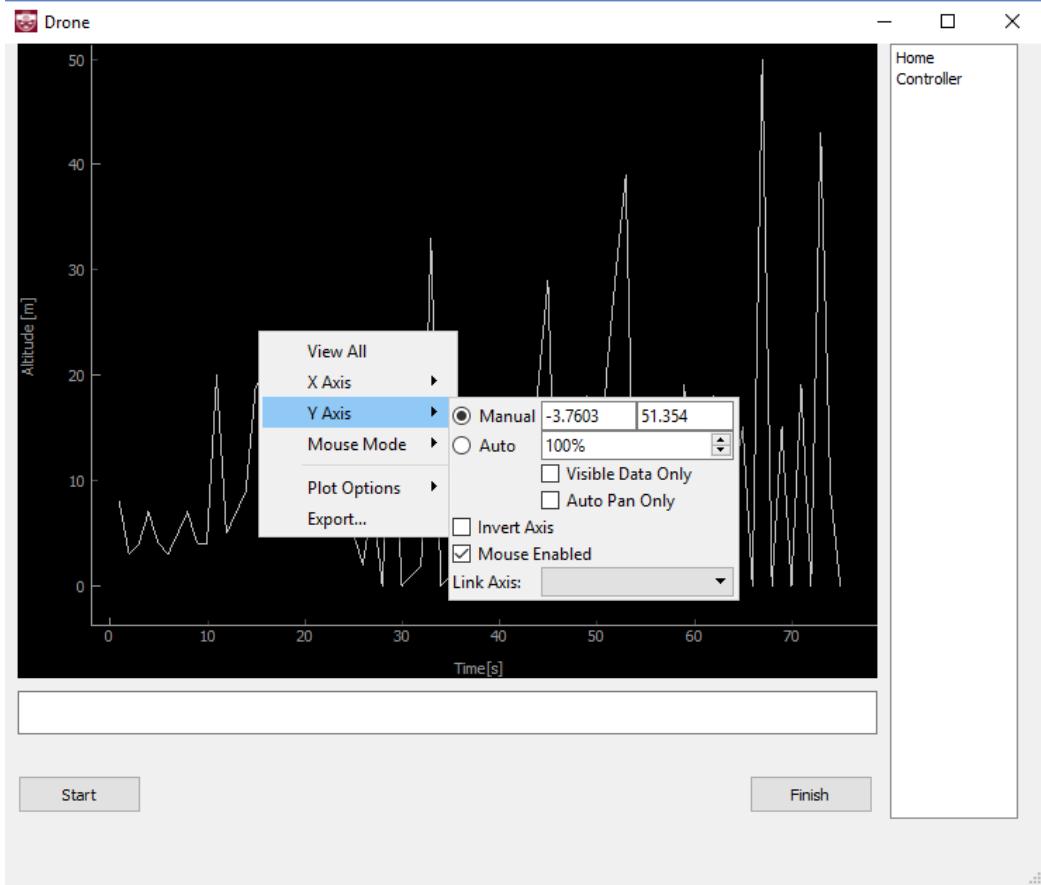


Figure 11: Display Y Values on Live Plot

5 Project Results

5.1 Simulations

5.1.1 Hover Test

Using the models and systems discussed in the previous subsection, our preliminary flight simulation was constructed. The Simulink model `Dynamic_Simulation.slx` was created. The altitude controller was tested by providing a step input. After some tuning of the controller, we were able to obtain the following step response.

When this test was initially performed, the SimScape MultiBody physical sim-

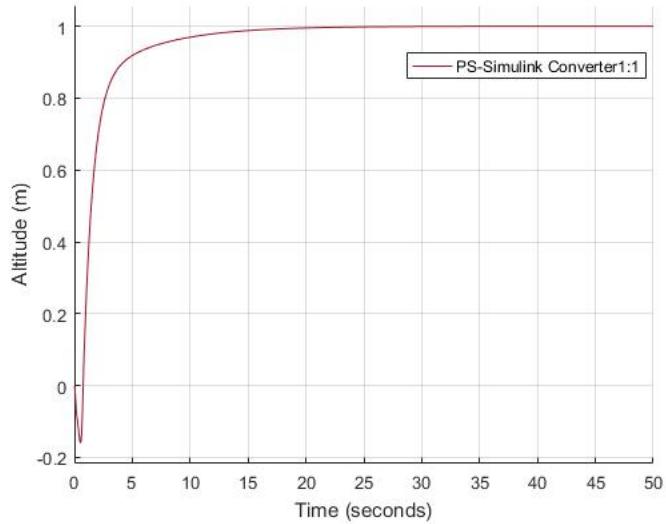


Figure 12: Hovering Step Response, for 1 metre altitude.

ulation did not yet include a model for a hard stop at the origin of the Z axis. This is to say that there was no representation of ground for the quad-rotor drone to rest upon. This is why an initial decline in position can be seen in the graph. This was subsequently added this term.

5.1.2 Translational Test

The translational test successfully showed that the pitch and roll tuning was performing well. Response to the control signal can be seen in either direction clearly, as well as a fast response. These can be seen in Figure 13.

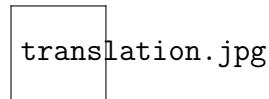


Figure 13: Error into pitch controller during translational test.

5.2 Physical Implementation

To date, several tests and proof of concepts have been performed to determine methods of controlling hardware, limitations of the hardware or software and to

determine feasibility of communication protocols. The test subjects include:

- Electronic Speed Controller
- Motor Lift Characteristics
- Wi-Fi Range
- Communication Channel
- Inertial Measurement Unit
- Miscellaneous Code Testing

5.2.1 Electronic Speed Controller

The Afro ESC 12Amp BEC UltraLite Multirotor ESC V3 was tested at St. Mary's University with the assistance of Dr. Rhinelander. An Arduino running a script to map a potentiometer to a PWM duty cycle was used as an attempt to control the motor through the ESC. A 12V power supply fed the ESC while the Arduino controlled the duty cycle of the speed controller producing a voltage output to control the motor speed.

The ESC testing was successful, the testing proved the Arduino's capability to control the motor with a variable input. The testing had flaws as a PWM duty cycle was used instead of a timed pulse width input. The duty cycle had potential of operating correctly as the range of times could have been calibrated to a range in the duty cycle although this method proved to be difficult due to low values causing the ESC to enter calibration mode. The script used to operate the ESC was re-written as a timed pulse width to ensure complete compatibility and ease of future integration. The pulse width script was tested using the ESC and was successful. The provided motor was successfully driven under no load conditions for the full range of pulse width values.

5.2.2 Motor Lift Characteristics

Using a 12V power supply, the provided ESC and the Multi-Star Elite motor the characteristics of the motor's lifting capacity were tested. A weight was attached to a support system with the motor and blade seated on top. The apparatus was placed on a scale and the scale's reading was zeroed. As the rotor speed increased, the reduction in weight read by the scale was considered the lift capacity.

The test was performed beginning at a pulse width of $1127\mu s$ which was found through experimentation to be the cut in pulse width for motor operation. The test was performed at increments of $25\mu s$. The resultant current draw values and

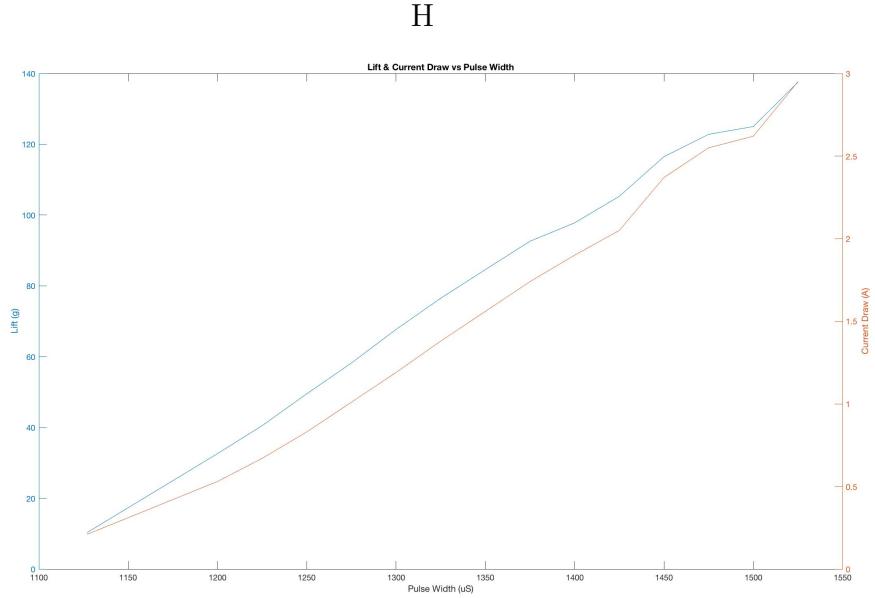


Figure 14: Motor Characterization Testing

lift values were documented. The lift values were used to create a simulink lookup table to characterize the motor's available force for simulation purposes.

During the load testing, it was noticed that the current draw from the individual motor was high. The power supply being used had a current limit of 3A therefore the maximum current draw allowed during testing was 2.95A to ensure no brown out due to lack of supply. The current limiting factor resulted in the test ending at a pulse width of $1525\mu\text{s}$ and a lift value of 137.5g. The resulting plot of the load testing is found in Figure 14.

5.2.3 Wi-Fi and Bluetooth Range

A simple proof of concept regarding the range of Wi-Fi communications was performed. The test incorporated a a Wi-Fi communicating camera tethered to a Wi-Fi output from a cell phone. A user walked down Spring Garden holding the cell phone and found the approximate distance at which the phone and the camera lost communication. It was found that the range was approximately 100 ft with line of sight available with no Wi-Fi boosting technology. Bluetooth communications were also tested using the Raspberry Pi 3 connected to a Playstation 4

controller although the communication channel held a strong connection for only approximately 10 ft, this distance was considered insufficient for the scope of the project.

5.2.4 Communication Channel Testing

Several tests to ensure the communication channels were operating correctly were performed. Testing of each communicating device were performed while scripting but an overall test was performed to be sure data was being transmitted from the joystick control input, through the Wi-Fi connection, over serial to the Arduino and finally writing to the ESCs. The testing of the channel was performed by use of an LCD screen connected to the Arduino, with the values received by the Arduino being written to the screen. Most recent testing produced slightly unexpected results, as the joystick controller seemed to have the control inputs mapped incorrectly. The test was considered successful as the altitude input performed as expected. Remapping of control inputs is required.

5.2.5 Inertial Measurement Unit Testing

The IMU was implemented and tested thoroughly for yaw, pitch, roll and altitude values. Altitude calculations were determined to be approximately +/- 50 cm in error without any filtering implemented. With an averaging filter implemented for the initial barometric pressure reading and a Kalman filter with feedback, the error was reduced to +/- 30 cm. Further filtering and testing of the altitude readings is to be performed. At low altitudes, +/- 30 cm error is considered too large as the stabilization PID loop will have difficulties when attempting to take off and land. Other measurement devices for low altitudes are going to be implemented and tested.

5.2.6 Flight and PID Testing

The drone was built and prepared for a flight test in a controlled environment at St. Mary's University. The test was performed with only the Altitude PID loop in operation, the goal was to ensure the drone would have enough thrust to achieve liftoff. It was expected that flight without pitch and roll stabilization would be unstable.

The results of testing proved that at 35 percent throttle the 470 gram drone achieves liftoff. The flight testing was considered a success and plans to perform a secondary flight test were made. The secondary test will incorporate the full control loop including the pitch and roll stabilization PID loops.

The pitch and roll PID loops have been bench tested with a current limited supply. It is apparent from the bench testing that the motors attempt to correct for variations in pitch and roll by increasing and decreasing specific motor throttles. It is unclear whether the attempts at stabilization are sufficient for flight. A flight test is required to determine the capabilities of the drone.

5.2.7 Miscellaneous Testing

All functions and scripts were tested to ensure compilation was possible and the program behaves as expected. Several tests and adjustments will be performed to ensure the device operates as expected prior to the submission of the final report.

5.3 Graphical User Interface

The main validation for the GUI was to ensure that each of the push buttons do the proper thing as well as when a page is selected from the list widget that the proper page is displayed. The testing involved with this was to select the desired push button or page and ensure the expected outcome happens. Along this process many software bugs were encountered and fixed, these included invalid syntax, improper use of libraries and just wrong implementation. Through these tests much was learned and the result was a GUI that provides all of the required functionality and is intuitive. After these were validated testing the live plotting capability was next.

5.3.1 Live Plotting Testing

Due to the new drone regulations proper flight tests to receive sensor data to live plot the altitude was unable to be performed. Instead, to validate that the plot on the seen in Figure 11 would update when new sensor data was received a test was developed. The test was to pull in data from a text file that was given in the form of x and y coordinates and then add new data to the text file as the GUI was running and make sure that the plot updated only when new data was available. The definition to pull in the data from the file can be found in the `liveData()` definition in the GUI code in APPENDIX.

The result of this test was positive, whenever new data when entered into the text file plot would update to include to new data point accurately and swiftly. A flaw with this test could be that when the sensor data is received it would not come in this form, in this case the script would have to be altered to allow for a different data form. This test proved that the plot can be updated in real time.

6 Discussion

6.1 Simulations

6.1.1 Roadblocks

For the most part, the implementation of the simulation went smoothly. However, progress on the simulation has hit a road block with respect to receiving the current orientation of the drone. These values are specifically from the SimScape MultiBody "Transform Sensor" block. As such, it is purely an issue with the simulation and will not be paralleled by the IMU implementation. When originally implemented this block, an output for axis orientation relative to the world frame was selected. It was not noticed that this output was a normalized unit vector. During this week leading to the design expo (March 30th), a block will be added to decode this vector into an appropriate pitch, roll, and yaw for use with our controller design.

6.1.2 Tuning

Tuning of the altitude controller, and subsequently this week with the other controllers, was performed by Simulating the plant then approximating it using Least Mean Squares. Although in our implementation of the design, our model of the pulsedwidth modulation is linearized by only accounting for the width of pulses in microseconds. Therefore it could be possible to linearize the plant of our model via other means. This method has the benefit that it would continue to work if the the PWM model was more evolved and include the discontinuities created by a PWM signal.

6.1.3 Controller Combination

As motors are paired on the diagonal to balance torque, the combination of control signals to each motor is non trivial. The altitude controller provides the baseline throttle, while the other controllers sum on top of this to create the output value. These summations are provided in the following table.

	Positive	Negative
Motor One	Pitch, Yaw	Roll
Motor Two	Yaw	Pitch, Roll
Motor Three	Pitch, Roll	Yaw
Motor Four	Roll	Yaw, Pitch

Table 1: Control Signal Combinations

6.1.4 3D Rendering

Currently the 3D rendering in place in the simulation is rudimentary. It consists of rendering a cross with four arms that are distinctly coloured. This allows for observing the orientation of the quad-rotor drone visually. Currently there is nothing else rendered in the 3D renderings. Improvements to this, are discussed in section 7.1.

6.2 Physical Implementation

The physical implementation of the drone components and software has been successful to date. The drone has a fully functional communication channel between a controller set point input through base station software to a Raspberry Pi computer over Wi-Fi. The Raspberry Pi also successfully relays the control information to the Arduino control loop to be processed.

The Arduino controller has been tested to poll an inertial measurement unit to determine the current states of yaw, pitch, roll and altitude. The initializations of all sensors, motors and communication channels operate as expected. The electronic speed controllers properly react to PWM inputs from the Arduino, controlling the four motors for quadcopter flight. Altitude measurements have been filtered reasonably well with room for improvement with regards to the tolerance of altitude error. Testing of new filtering methods is to be performed. The Arduino successfully repackages the received bytes into floating point values for use in the PID loop, to be outputted to the motors.

The PID implementation has been tested, the drone reacts to altitude, yaw and pitch variations as expected although stable flight testing has yet to be achieved. Bench testing of the drone without propellers has proved that the drone attempts to stabilize to an altitude set point as well as an appropriate orientation. The PID implementation compares the set points provided to the gathered data from the inertial measurement unit. All software packages produced throughout the project can be seen in Appendix B. The design of the PID loops can be seen in the simulation section of the appendices, Appendix A.

6.3 Graphical User Interface

The implementation of the GUI has been successful to date. The GUI achieves has the ability to initialize communications between the base station host and Raspberry Pi 3, plot live data and initialize manual control which are all the required features. These functions have been confirmed through the testing outlined in section 5.3.

The ability to pull live data from the sensors has yet to be tested but from the results of the live plotting tests we are confident that this will be achievable. The GUI implementation to this point has been a success, the software that governs the behaviour can be found in Appendix D.1.

6.3.1 Timing & Testing

Although the first semester schedule was adhered to quite well, the second semester schedule was not nearly as reflective of the actual timings. The workloads of other courses were compounded by weather closures. Additionally, the date of the coming expo taking place in March as opposed to April forced additional rescheduling.

Unfortunately our original planned flight tests were first delayed by our simulation errors as well as delays in the assembling of the drone. As if these were not unfortunate enough the regulations that govern restrictions on the flight of unmanned aerial vehicles was update earlier this month. As such we were forced to cancel our original test plans and opt for more simplistic proof of concepts tests that do not involve flight. With the updated regulations that came into effect, it is not legal for us to perform our original test plans.

7 Future Recommendations

7.1 Simulations

The 3D rendering could be dramatically improved in two ways. Firstly, a series of references could be added. These would include a ground, and some mock buildings. This would allow for a better sense of scale and movement during the simulation. Should time allow this will be implemented by the submission of the final revision of the report.

The second improvement to the simulation would be a more realistic rendering of the quad-rotor drone. As mentioned previously, the current rendering is rudimentary at best. Improving this would be mostly cosmetic, but could be done to match the drone being used. With the addition of disturbances a better physical model and rendering of the drone would be beneficial beyond the cosmetic, as it would allow for the effects of the disturbances to be more easily comprehended.

Disturbances could be added to the simulation to represent wind, collisions, and failures. This would allow for the controller's to be tested in simulation to a more robust degree. Additionally it would allow for the development of another controller layer that could alter the existing design based on sensor data or determined failures.

7.2 Physical Implementation

Future recommendations for the physical implementation of the drone include:

- Camera Implementation (Raspberry Pi Camera V2 Recommended)
- Better Filtering of Altitude Measurements Incorporate Accelerometer - Barometer Kalman Filter
- Design Mounting Case for Arduino, RPi and Required Sensors on Drone
- Implement Condition Monitoring (Temperature, Battery Level, etc.)
- Monitor I2C Bus with RPi to Gather IMU Data and Send to GUI
- Implement Interrupt for PID Loop Timing
- Test Flight in Controlled Environment

The groundwork for a successful drone flight controller environment has been laid, with more time several areas of research and development have the potential to be improved upon and perfected.

7.3 Graphical User Interface

Some future recommendations for the GUI have been mentioned throughout the report, but a more complete list of improvements is presented below.

- Manipulate and Display PI and PID Parameters
- Display Sensor Status
- Display Flight Time
- Display GPS Coordinates
- Display Battery Level of the Drone

A GUI including the features listed above on top our the features our GUI has would make for a very strong and informative GUI. Given more time these areas could have been explored and potentially included in our design, but our GUI includes the key features for our clients purposes.

8 Conclusion

Although there are plenty of existing quad-rotor drone controllers, some of which that can even handle a varied amount of rotors. The process of developing our own, without "looking under the hood" of existing controllers has been both exciting and difficult. To this date, we have built the ground work of for a flight controller capable of controlling the pitch, roll, yaw, and altitude of a quad-rotor drone. While, only altitude control remains tested to this date. As the term is not yet finished; We continue to hope to finish the control of the remaining controllers, as well as putting them under a proof of concept test. As well as polishing the interfaces to handle sensor data feedback and controller parameter updates.

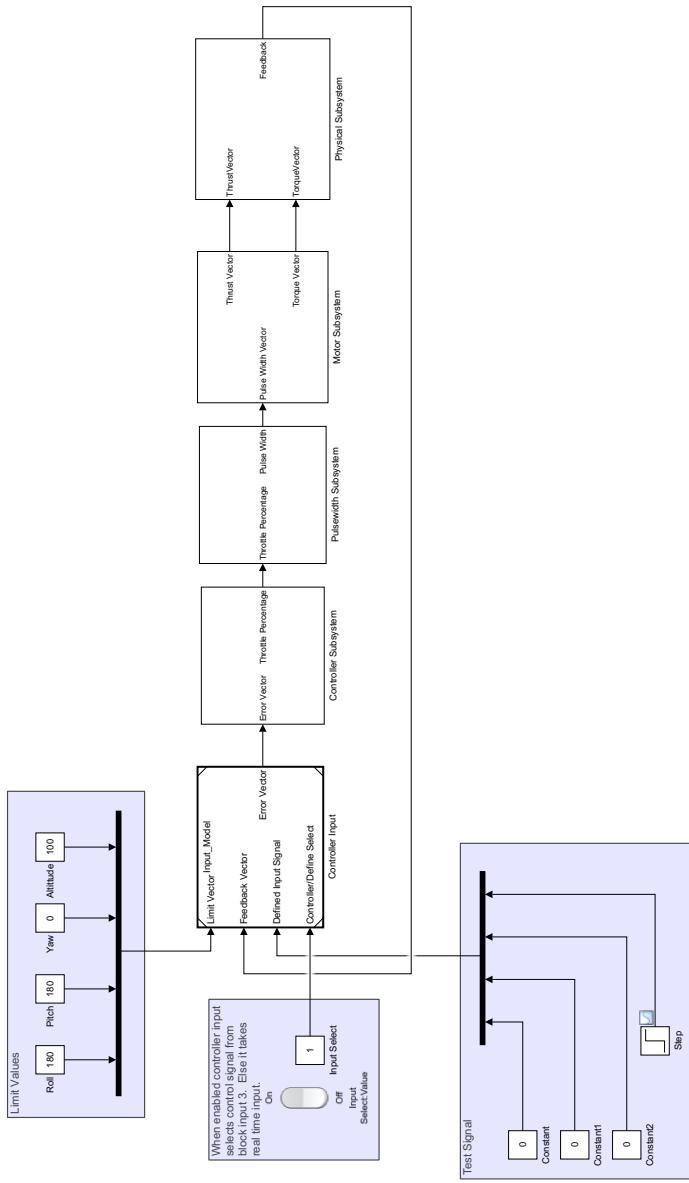
We would like to thank Dr. Jason Rhinelander, for the opportunity and support through the past 8 months. As well as Preston Stronarch for his suggestions and aid during testing.

A References

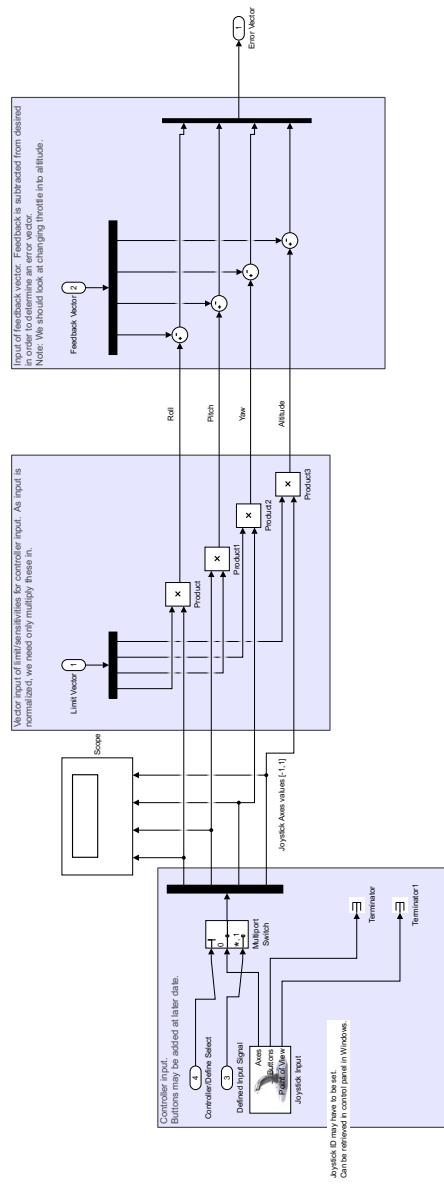
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B Simulink Models

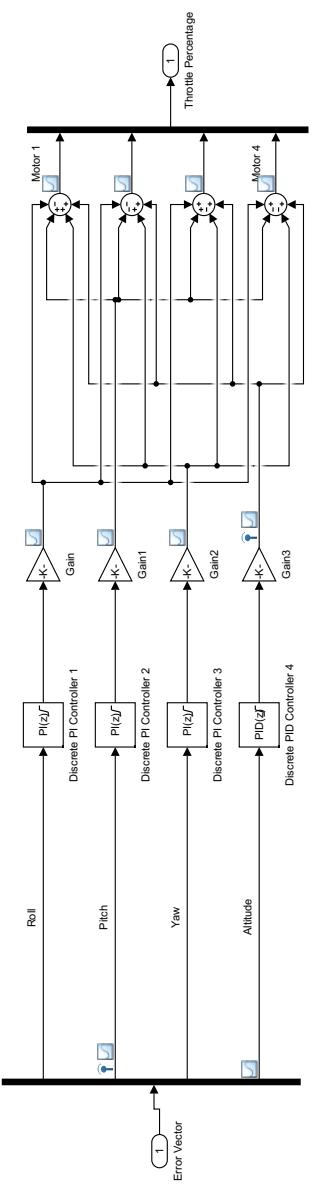
B.1 Dynamic Simulation



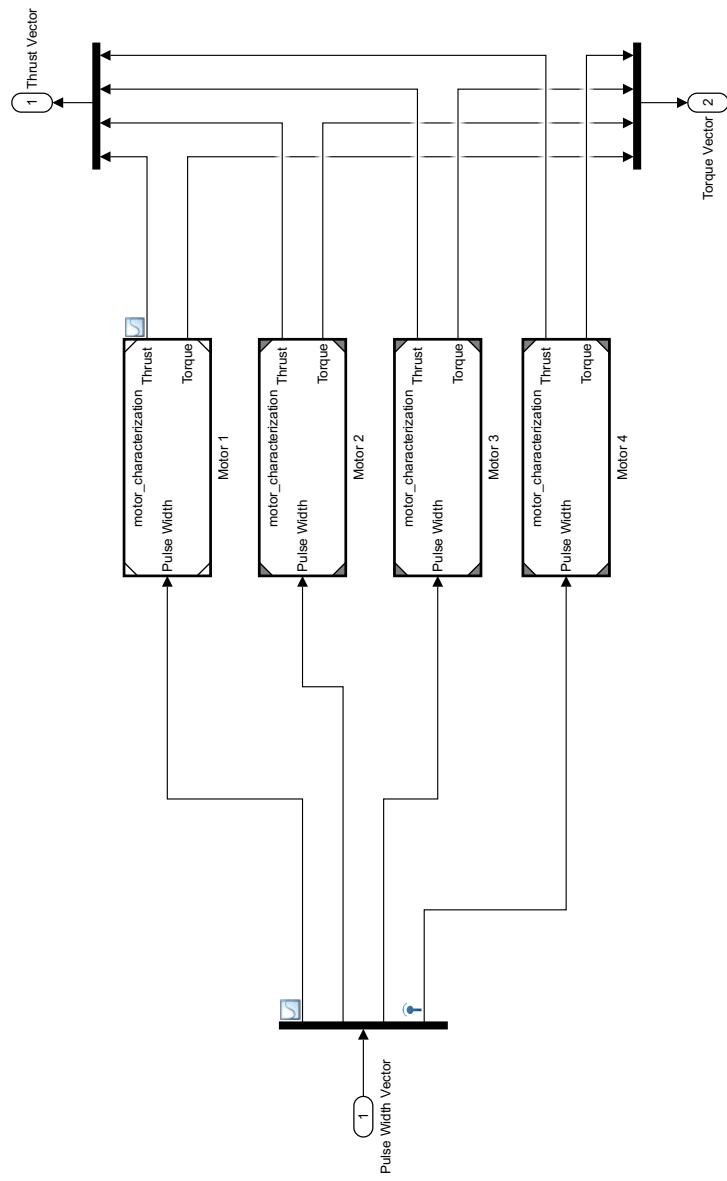
B.2 Input Model Subsystem



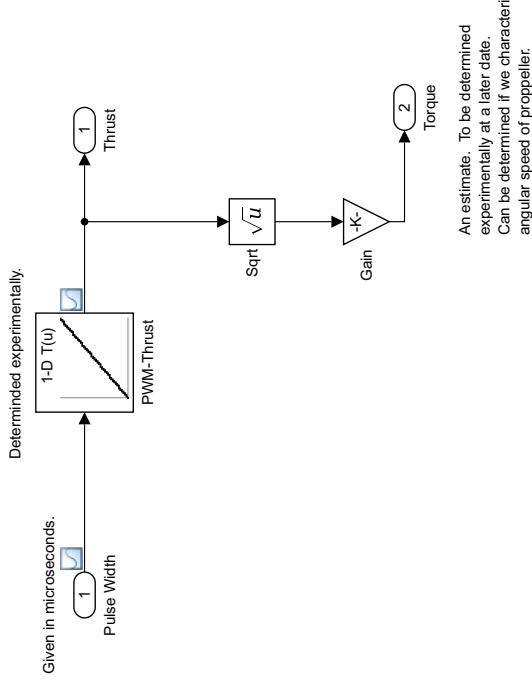
B.3 Controller Subsystem



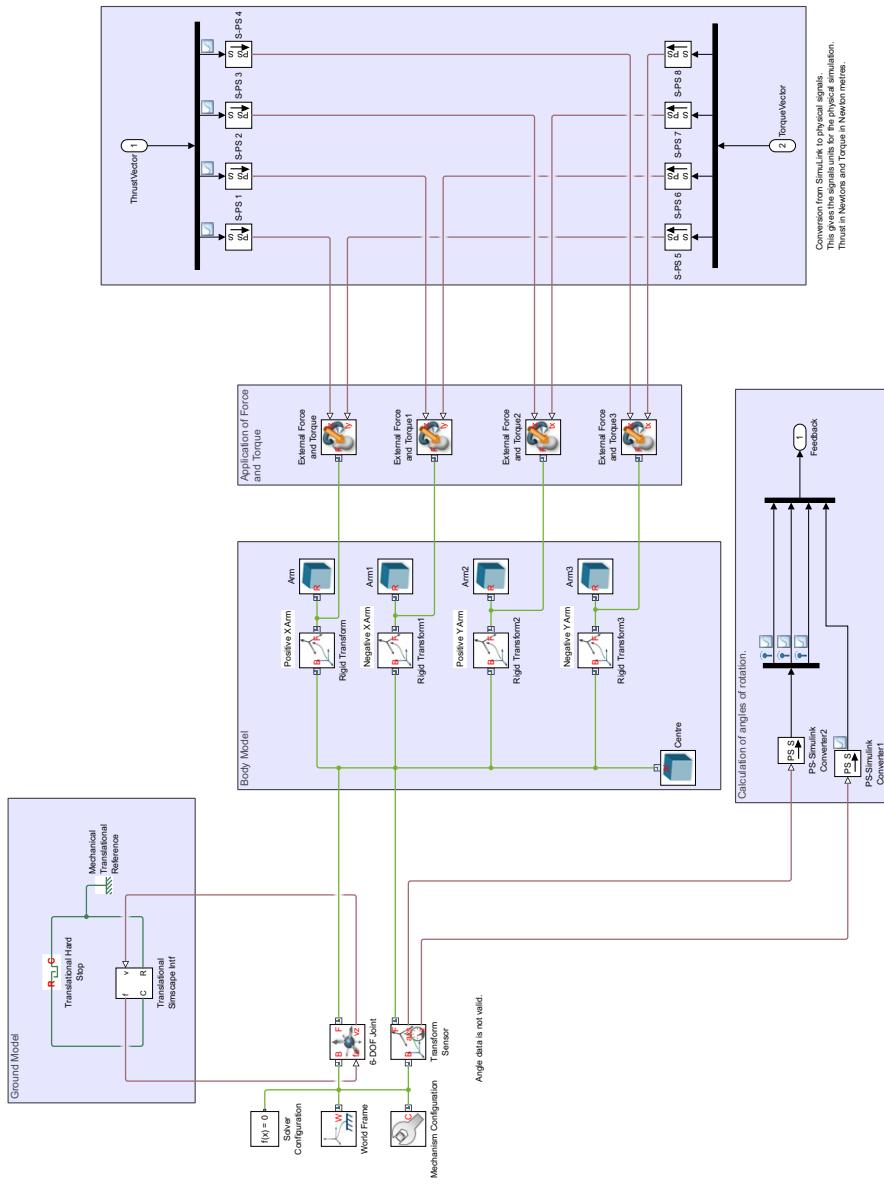
B.4 Motor Subsystem



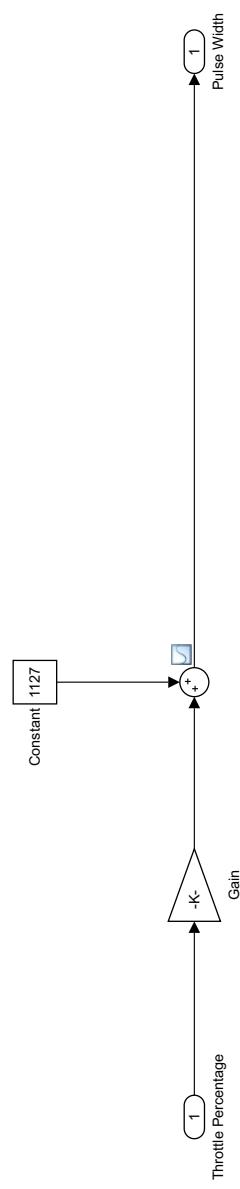
B.5 Motor Characterization Model



B.6 Physical Subsystem



B.7 Pulsewidth Subsystem



C Software Packages

C.1 Arduino Library

Listing 1: Drone.h Arduino Header File

```
/*
  Drone.h - Library for Drone Controller.
  Created by Lucas Doucette, February 17, 2017.
*/
#ifndef Drone_h
#define Drone_h

#include "Arduino.h"
#include <Wire.h>
#include <Servo.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_LSM303_U.h>
#include <Adafruit_BMP085_U.h>
#include <Adafruit_L3GD20_U.h>
#include <Adafruit_10DOF.h>

class Drone
{
public:
    Drone();
    float get_sensorRoll();
    float get_sensorPitch();
    float get_sensorYaw();
    float get_sensorAltitude(float startingPressure);
    float get_currentPressure();
    float PID_Calculate(float Setpoint, float SenseRead, float kp, float kd, float ki );
    float PID_FWD_EULER_Calculate(float Setpoint, float SenseRead, float kp, float kd, float ki, float Ts, float N);
    float Altitude_Calibration(float AltitudePID);
    float PR_Calibration(float PR_PID);
    void read_PS4Setpoints(float *PS4Yaw, float *PS4Pitch, float *PS4Roll, float *PS4Altitude);
    void initSensors();
    void initESCs(Servo esc_1, Servo esc_2, Servo esc_3, Servo esc_4);
    float read_float();
    void send_float(float arg);
    float ping_ultrasonic();

};

#endif
```

Listing 2: Drone.cpp Arduino Library File

```

/*
Drone.h - Library for Drone Controller.
Created by Lucas Doucette , February 17, 2017.
*/
#include "Arduino.h"
#include "Drone.h"
#include <Wire.h>
#include <Servo.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_LSM303_U.h>
#include <Adafruit_LSM303.h>
#include <Adafruit_BMP085_U.h>
#include <Adafruit_L3GD20_U.h>
#include <Adafruit_10DOF.h>
#include <LiquidCrystal.h>

/* Assign a unique ID to the sensors */
Adafruit_10DOF dof = Adafruit_10DOF();
Adafruit_LSM303_Accel_Unified accel = Adafruit_LSM303_Accel_Unified(30301);
Adafruit_LSM303_Mag_Unified mag = Adafruit_LSM303_Mag_Unified(30302);
Adafruit_BMP085_Unified bmp = Adafruit_BMP085_Unified(18001);

sensors_event_t accel_event;
sensors_event_t mag_event;
sensors_event_t bmp_event;
sensors_vec_t orientation;

float temperature;

Drone::Drone()
{
}

float Drone::ping_ultrasonic()
{
    long duration , m;

    //send low high low to ensure a clean ping

    pinMode(7, OUTPUT);
    digitalWrite(7, LOW);
    delayMicroseconds(2);
    digitalWrite(7, HIGH);
    delayMicroseconds(5);
    digitalWrite(7, LOW);

    pinMode(8, INPUT);
    duration = pulseIn(8, HIGH);

    //29 microseconds per cmeter, and round trip
    m=(duration/29)/2;

    if(m>1500)
    {
        m=0;
    }
    return m;
}

float Drone::get_sensorRoll()
}

```

```

{
    float sensorRoll;

    // Calculate pitch and roll from the raw accelerometer data
    accel.getEvent(&accel_event);
    if (dof.accelGetOrientation(&accel_event, &orientation))
    {
        // 'orientation' should have valid .roll and .pitch fields
        sensorRoll=orientation.roll;
        return sensorRoll;
    }

    float Drone::get_sensorPitch()
    {
        float sensorPitch;

        // Calculate pitch and roll from the raw accelerometer data
        accel.getEvent(&accel_event);
        if (dof.accelGetOrientation(&accel_event, &orientation))
        {
            // 'orientation' should have valid .roll and .pitch fields
            sensorPitch=orientation.pitch;
            return sensorPitch;
        }
    }

    float Drone::get_sensorYaw()
    {
        float sensorYaw;

        // Calculate the heading using the magnetometer
        mag.getEvent(&mag_event);
        if (dof.magGetOrientation(SENSOR_AXIS_Z, &mag_event, &orientation))
        {
            // 'orientation' should have valid .heading data now
            sensorYaw=orientation.heading;
            return sensorYaw;
        }
    }

    float Drone::get_sensorAltitude(float startingPressure)
    {
        float sensorAltitude, NowPressure;
        // kalman filtering variables
        float Variance=0.108923435;
        float varProcess = 1e-12;
        float Pc = 0.0;
        float G = 0.0;
        float P = 1.0;
        float Xp = 0.0;
        float Zp = 0.0;
        float Xe = 0.0;

        // Calculate the altitude using the barometric pressure sensor
        bmp.getEvent(&bmp_event);
        NowPressure=bmp_event.pressure;
    }
}

```

```

// Get ambient temperature in C
bmp.getTemperature(&temperature);

// Convert atmospheric pressure, SLP and temp to altitude
sensorAltitude=bmp.pressureToAltitude(startingPressure ,NowPressure ,temperature);

// kalman filter ;
Pc=P+varProcess;
G=Pc/(Pc+Variance);
P=(1-G)*Pc;
Xp=Xe;
Zp=Xp;
Xe=ping_ultrasonic()/100;

if (Xe >= 2.0)
{
    //Enable barometric pressure above 2 meters
    Xe=G*(sensorAltitude-Zp)+Xp;
}

return Xe;

}

//must be called after initSensors();

float Drone::get_currentPressure()
{
    float currentPressure;

//Initializing Pressure , Filtered for accuracy
//Smoothing Constant

const int numReadings=1;
float SmoothingVariable=0;
float NowPressure=0;

bmp.getEvent(&bmp_event);
for(int i=0; i<numReadings; i++)
{
    SmoothingVariable+=bmp_event.pressure;
    //delay (i);
}

currentPressure = SmoothingVariable/numReadings;
SmoothingVariable=0;

return currentPressure;
}

float Drone::PID_Calculate(float Setpoint , float SenseRead , float kp , float kd , float ki)
{
    //Define PID Variables
    float Error , DError , IError , LastTime ,LastError , Output;

    //find current time
    unsigned long NowTime = millis();

    //calculate PID Error values
    Error = Setpoint-SenseRead;
    DError = (Error-LastError)/(NowTime-LastTime);
    IError += (Error*(NowTime-LastTime));

    //Calculate Output
    Output = kp*Error+ki*IError+kd*DError;

    //Save LastTime and LastError
    LastTime=NowTime;
    LastError=Error;
}

```

```

//Requirement based on Simulink
Output=(Output/9000)*(1860 - 1127);

if( Output>=1200){
    Output = 1200;
}
if( Output<=1127)
{
    Output=1127;
}

return Output;
}

float Drone::PID_FWD_EULER_Calculate(float Setpoint, float SenseRead, float kp, float kd, float ki, float Ts, float
{
    float e2, e1, e0, u2, u1, u0; // Variables for PID computation
    float a0, a1, a2, b0, b1, b2, ku1, ku2, ke0, ke1, ke2;

    /* hand calculated forward euler coefficients
    a0 = (1 - N*Ts);
    a1 = (N*Ts - 2);
    a2 = (1);
    b0 = (kp*(1 - N*Ts)+ki*(N*Ts-1)+kd*N);
    b1 = (kp*(N*Ts-2)+ki*Ts-2*kd*N);
    b2 = (kp+kd*N);
    ku1 = a1/a0; ku2 = a2/a0; ke0 = b0/a0; ke1 = b1/a0; ke2 = b2/a0;

    /* Backward Euler for testing
    a0 = (1+N* Ts);
    a1 = -(2 + N* Ts);
    a2 = 1;
    b0 = kp*(1+N* Ts) + ki* Ts*(1+N* Ts) + kd*N;
    b1 = -(kp*(2+N* Ts) + ki* Ts + 2* kd*N);
    b2 = kp + kd*N;
    ku1 = a1/a0; ku2 = a2/a0; ke0 = b0/a0; ke1 = b1/a0; ke2 = b2/a0;
    */

    //update variables
    e2=e1;
    e1=e0;
    u2=u1;
    u1=u0;

    //calculate error and output
    e0 = Setpoint - SenseRead;
    u0 = - ku1*u1 - ku2*u2 + ke0*e0 + ke1*e1 + ke2*e2;

    //return output
    return u0;
}

float Drone::Altitude_Calibration(float AltitudePID)
{
    AltitudePID=(AltitudePID /9000)*(1860 - 1127);

    if (AltitudePID > 1860)
    {
        AltitudePID = 1860;
    }

    if (AltitudePID < 1127)
    {

```

```

        AltitudePID = 1127;
    }

    return AltitudePID;
}

float Drone::PR_Calibration(float PR_PID)
{
    if (PR_PID > 4500)
    {
        PR_PID = 4500;
    }

    if (PR_PID < -4500)
    {
        PR_PID = -4500;
    }

    return (PR_PID/9000);
}

void Drone::read_PS4Setpoints(float *PS4Yaw, float *PS4Pitch, float *PS4Roll, float *PS4Altitude)
{
    //Write serially to Pi to begin transmission.

    byte XMIT = 00000001;

    if (Serial.available())
    {
        Serial.write(XMIT);
    }

    while (Serial.available())
    {
        for(int i=0; i<4; i++)
        {
            *PS4Yaw=read_float();

        }

        for(int i=4; i<8; i++)
        {
            *PS4Pitch=read_float();

        }

        for(int i=8; i<12; i++)
        {
            *PS4Roll=read_float();

        }

        for(int i=12; i<16; i++)
        {
            *PS4Altitude=read_float();
        }
    }
}

void Drone::initSensors()

```

```

{

if (!accel.begin())
{
    /* There was a problem detecting the LSM303 ... check your connections */
    Serial.println(F("Ooops, _no_LSM303_detected_..._Check_your_wiring!"));
    while(1);
}

if (!mag.begin())
{
    /* There was a problem detecting the LSM303 ... check your connections */
    Serial.println(F("Ooops, _no_LSM303_detected_..._Check_your_wiring!"));
    while(1);
}

if (!bmp.begin())
{
    /* There was a problem detecting the BMP180 ... check your connections */
    Serial.println(F("Ooops, _no_BMP180_detected_..._Check_your_wiring!"));
    while(1);
}

void Drone::initESCs(Servo esc_1, Servo esc_2, Servo esc_3, Servo esc_4)
{

    //Initialization of the ESCs
    esc_1.writeMicroseconds(1860);
    esc_2.writeMicroseconds(1860);
    esc_3.writeMicroseconds(1860);
    esc_4.writeMicroseconds(1860);
    delay(3000);
    esc_1.writeMicroseconds(1060);
    esc_2.writeMicroseconds(1060);
    esc_3.writeMicroseconds(1060);
    esc_4.writeMicroseconds(1060);
    delay(3000);

}

void Drone::send_float (float arg) {
    byte * data = (byte *) &arg;
    Serial.write(data, sizeof(arg));
}

float Drone::read_float () {
    union{
        float a;
        unsigned char bytes[4];
    } data;
    for (int i=0; i<4; i++) {
        data.bytes[i] = Serial.read();
    }
    float test = data.a;
    return(test);
}
}

```

C.2 Arduino Main File

Listing 3: Main.ino Drone Flight Program

```
#include <Drone.h>
#include "TimerOne.h"

Drone drone;
Servo esc_1, esc_2, esc_3, esc_4;
int MotorPin1=6, MotorPin2=9, MotorPin3=5, MotorPin4=3;
float Yaw_Setpoint, Pitch_Setpoint, Roll_Setpoint, Altitude_Setpoint;
float Current_Yaw, Current_Pitch, Current_Roll, Current_Altitude;
float initial_pressure;
float kp_alt=17257.712, ki_alt=2752.7, kd_alt=12500, N_alt=20;
float kp_PR=-24.3498729396233, ki_PR=-15.1642535450127, kd_PR=-7.30148358076729, N_PR=44.9852981416911;
float AltitudePID, PitchPID, RollPID;
float Ts = 0.0001;
float Alt_Out, Pitch_Out, Roll_Out;
float Motor1_Output, Motor2_Output, Motor3_Output, Motor4_Output;

void setup() {
    esc_1.attach(MotorPin1); //set up motor connections & Initialize
    esc_2.attach(MotorPin2);
    esc_3.attach(MotorPin3);
    esc_4.attach(MotorPin4);
    drone.initESCs(esc_1, esc_2, esc_3, esc_4);
    //Initialize Serial Bus and IMU Sensors
    Serial.begin(9600);
    drone.initSensors();
    initial_pressure=drone.get_currentPressure();

    //initialize timer and interrupt callback
    //Timer1.initialize(100);
    //Timer1.attachInterrupt(PID_Interrupt);

}

//Commented until troubleshooting is complete
/*void PID_Interrupt(){
    AltitudePID = drone.PID_FWD_EULER_Calculate(Altitude_Setpoint, Current_Altitude, kp, kd, ki, Ts);
    esc_1.writeMicroseconds(AltitudePID);
    esc_2.writeMicroseconds(AltitudePID);
    esc_3.writeMicroseconds(AltitudePID);
    esc_4.writeMicroseconds(AltitudePID);
}

*/
void loop() {

    //Get Control Setpoints
    if (Serial.available()==0)
    {
        Serial.print('c');
    }

    while (Serial.available()>0)
    {
        Yaw_Setpoint = drone.read_float();
        Pitch_Setpoint = drone.read_float();
        Altitude_Setpoint = drone.read_float();
        Roll_Setpoint = drone.read_float();
    }
}
```

```

Altitude_Setpoint = 0.50;
Pitch_Setpoint=0;
Roll_Setpoint=0;

//Gather IMU Data
Current_Yaw = drone.get_sensorYaw();
Current_Pitch = drone.get_sensorPitch();
Current_Altitude = drone.get_sensorAltitude(initial_pressure);
Current_Roll = drone.get_sensorRoll();

//Calculate PID's and calibrate outputs based on simulink requirements.

AltitudePID = drone.PID_FWD_EULER_Calculate(Altitude_Setpoint, Current_Altitude, kp_alt, kd_alt, ki_alt, Ts, N_alt
Alt_Out = drone.Altitude_Calibration(AltitudePID);

PitchPID = drone.PID_FWD_EULER_Calculate(Pitch_Setpoint, Current_Pitch, kp_PR, kd_PR, ki_PR, Ts, N_PR);
Pitch_Out=drone.PR_Calibration(PitchPID);

RollPID = drone.PID_FWD_EULER_Calculate(Roll_Setpoint, Current_Roll, kp_PR, kd_PR, ki_PR, Ts, N_PR);
Roll_Out = drone.PR_Calibration(RollPID);

//PID Combination as required by simulink

Motor1_Output = Alt_Out + Pitch_Out - Roll_Out;
Motor2_Output = Alt_Out - Pitch_Out - Roll_Out;
Motor3_Output = Alt_Out + Pitch_Out + Roll_Out;
Motor4_Output = Alt_Out - Pitch_Out + Roll_Out;

//Output PID Results to motors

esc_1.writeMicroseconds(Motor1_Output);
esc_2.writeMicroseconds(Motor2_Output);
esc_3.writeMicroseconds(Motor3_Output);
esc_4.writeMicroseconds(Motor4_Output);

}

```

C.3 Raspberry Pi Scripts

Listing 4: Server.py Raspberry Pi Communication Server

```
import socketserver
import sys
import arduino
import threading
import queue
from subprocess import check_output

#TODO:
#    Control Side
#        Write Server w/ logging
#        Test
#    Backchannel
#        Write Handler
#        Test
#    Read
#        TCP Binding

class SerialRequestHandler(threading.Thread):
    def __init__(self, stateq):
        super(self.__class__, self).__init__()
        self.stateq = stateq

    def run(self):
        #TODO: Add poison pill to exit thread
        sbus = arduino.Arduino_Controller(9600)
        while True:
            ready = sbus.ready()
            if ready:
                sbus.serial_bus.read(ready)
                sbus.serial_bus.write(self.stateq.get())

class QuadControlHandler(socketserver.BaseRequestHandler):
    def __init__(self, request, client_address, server, stateq):
        self.stateq = stateq
        super(self.__class__, self).__init__(request, client_address, server)
        return

    def handle(self):
        if self.stateq.full():
            self.stateq.get() #Queue has size of 1, if full clear for new state
        recv = self.request.recv(16)
        self.stateq.put(recv)
        print('Received:' + str(recv))
        return

class QuadControlServer(socketserver.TCPServer):
    def __init__(self, server_address, RequestHandlerClass):
        super(self.__class__, self).__init__(server_address, RequestHandlerClass)
        self.controller = arduino.Arduino_Controller(9600)
        self.stateq = queue.Queue(1)
        return

    def serve_forever(self, poll_interval=0.5):
        thread = SerialRequestHandler(self.stateq)
        thread.start()
        super(self.__class__, self).serve_forever(poll_interval)
        return

    def finish_request(self, request, client_address):
        self.RequestHandlerClass(request, client_address, self, self.stateq)

if __name__ == '__main__':
    if sys.version_info[0] < 3:
        raise Exception('Version Error', 'Not compatible with Python version 2')

HOST = check_output(['hostname', '-I']).strip()
```

```
CONTROLPORT = 2222
COMMS.PORT = 4444

test_serv = QuadControlServer((HOST, CONTROLPORT), QuadControlHandler)
test_serv.serve_forever()
```

Listing 5: arduino.py Raspberry Pi Serial Communication Library

```
# 2017-01-13 Auth: Dylan
import serial

class Arduino_Controller(object):
    # Provides a wrapper for communicating with the Arduino over I2C/SMBUS.
    def __init__(self, baud):
        self.baudrate = baud
        self.serial_bus = serial.Serial('/dev/ttyACM0', self.baudrate)

    def write_axes(self, axes):
        self.serial_bus.write(axes)

    def ready(self):
        return self.serial_bus.inWaiting()

    def write_button(self, button):
        pass
```

C.4 Base Station Communication Script

Listing 6: Control Signal and Client Script

```

#!/usr/bin/env python
# -*- coding: utf-8 -*-
#
# This file presents an interface for interacting with the Playstation 4 Controller
# in Python. Simply plug your PS4 controller into your computer using USB and run this
# script!
#
# NOTE: I assume in this script that the only joystick plugged in is the PS4 controller.
#       if this is not the case, you will need to change the class accordingly.
#
# Copyright    2015 Clay L. McLeod <clay.l.mcleod@gmail.com>
#
# Distributed under terms of the MIT license.

#TODO:
#   rewrite connection for new server
#   test

# import os
# import pprint
import pygame
import socket
import struct
import sys

if sys.version_info[0] < 3:
    raise Exception('Lucas', 'not_compatible_with_Python_version_2')

class PS4Controller(object):
    """Class representing the PS4 controller. -Pretty straightforward functionality."""

    controller = None
    axis_data = None
    button_data = None
    hat_data = None

    def __init__(self, axis_order=[1, 2, 3, 4], hostname='raspberrypi', port=2222):
        """Initialize the joystick components"""

        pygame.init()
        pygame.joystick.init()
        self.controller = pygame.joystick.Joystick(0)
        self.controller.init()
        self.hostname = hostname
        self.port = port
        if isinstance(axis_order, list):
            self.axis_order = axis_order # For changing how controller axes are bound
        else:
            raise Exception(TypeError, 'axis_order must be list.')
    def update_axes(self, axis_order):
        self.axis_order = axis_order

    def listen(self):
        """Listen for events to happen"""

        if not self.axis_data:
            self.axis_data = {0: float(0),
                             1: float(0),
                             2: float(0),
                             3: float(0),
                             4: float(-1),
                             5: float(-1)} # Added explicit number of axes to avoid waiting for input

        if not self.button_data:
            self.button_data = {}
            for i in range(self.controller.get_numbuttons()):
                self.button_data[i] = False

        if not self.hat_data:

```

```

    self.hat_data = {}
    for i in range(self.controller.get_numhats()):
        self.hat_data[i] = (0, 0)

# host = '192.168.2.19' #ip of Server (PI)
host = socket.gethostname() # if fails install samba on pi and reboot

while True:
    for event in pygame.event.get():
        if event.type == pygame.JOYAXISMOTION:
            self.axis_data[event.axis] = round(event.value, 2)
        elif event.type == pygame.JOYBUTTONDOWN:
            self.button_data[event.button] = True
        elif event.type == pygame.JOYBUTTONUP:
            self.button_data[event.button] = False
        elif event.type == pygame.JOYHATMOTION:
            self.hat_data[event.hat] = event.value

    # Insert your code on what you would like to happen for each event here!
    # In the current setup, I have the state simply printing out to the screen.

    # Defining Variables to send through the socket to the RPi, need to be strings

    # axis_data=str(self.axis_data)
    # button_data = str(self.button_data)
    # hat_data = str(self.hat_data)

    # Sending Data over a socket to the RPi
    # print(str(self.axis_data))
    # Isolate desired Axes

    axes_data = [self.axis_data[self.axis_order[0]],
                 self.axis_data[self.axis_order[1]],
                 self.axis_data[self.axis_order[2]],
                 self.axis_data[self.axis_order[3]]]
    byte_data = [] # To hold the axes data serialized to bytes
    for axis in axes_data:
        byte_data.append(struct.pack("f", axis)) # F for float

    xmission_bytes = bytes().join(byte_data)
    connection = socket.socket()
    connection.connect((host, self.port))
    connection.send(xmission_bytes) # sending the controller data over the port
    connection.close()
    # print(xmission_bytes)

    # os.system('cls')
    # break
    # s.send(button_data)
    # s.send(hat_data)
    # s.close()

if __name__ == "__main__":
    ps4 = PS4Controller()
    # ps4.init()
    ps4.listen()

```

D GUI

D.1 GUI Code

Listing 7: GUI.py

```
#Written by Brendon Camm, last updated April 9th, 2017

import sys
from PyQt5 import QtCore, QtGui, uic, QtWidgets
import numpy as np
import time
import struct
import socket
from PS4_Controller import PS4Controller as PS4
import pyqtgraph as pg
import pyqtgraph.exporters

qtCreatorFile = "GUI.ui" # Enter QtDesigner file here.
Ui_MainWindow, QtBaseClass = uic.loadUiType(qtCreatorFile)

class GUI(QtWidgets.QMainWindow, Ui_MainWindow, QtWidgets.QMenu):
    def __init__(self):
        super(GUI, self).__init__()
        #Qt initialization
        QtWidgets.QMainWindow.__init__(self)
        Ui_MainWindow.__init__(self)
        self.page = QtWidgets.QStackedWidget()
        self.setCentralWidget(self.page)
        self.setupUi(self)
        self.setWindowTitle("Drone")
        self.setWindowIcon(QtGui.QIcon('smu.png'))

    #Networking
    self.getHost = socket.gethostname()
    self.staticPort = '1247'

    #Main Page buttons
    self.start.clicked.connect(self.connection)
    self.end.clicked.connect(self.stop)

    #Listing widget, allows for the user to select a certain page
    self.list.insertItem(0, 'Home')
    self.list.insertItem(1, 'Controller')
    self.list.currentRowChanged.connect(self.display) #Changes widget index to appropriate page

    #Controller Page
    self.axisVal.setText('1-2-3-4')
    self.hostVal.setText(self.getHost)
    self.portVal.setText(self.staticPort)
    self.axisMenu.clicked.connect(self.axisSettings) #When "Update Axis" is clicked call definition axisSettings
    self.hostMenu.clicked.connect(self.hostSettings) #When "Update host" is clicked call definition hostSettings
    self.portMenu.clicked.connect(self.portSettings) #When "Update Port" is clicked call definition portSettings
    self.updateConnect.clicked.connect(self.updateConnection) #When "Update Connection" is clicked call definition updateConnection
    self.connectPS4.clicked.connect(self.connectController) #When "Manual Control" is clicked call definition connectController

    #Live plotting Initializations
    self.initplt()
    self.plotcurve = pg.PlotDataItem()
    self.plotwidget.addItem(self.plotcurve)
    self.t = 0
    self.update1()
    self.timer = pg.QtCore.QTimer()
    self.timer.timeout.connect(self.move) # Connects a timer to the "move" definition that allows for live plotting
    self.timer.start(1000) # Poll for updates of new data every 1000 milliseconds (1 second)

    def stop(self):
        sys.exit(app.exec_())

    def connection(self):
```

```

s = socket.socket()
host = self.getHost
port = int(self.staticPort)
status = s.connect_ex((host, port)) #Returns 0 if connect is successful, returns errno if not
if status: # Status = errno
    self.thisworks.setText("Connection_Unsuccessful")
    self.connectionStat.setText("Communications_have_not_been_established")
else: # Status = 0
    print(status)
    self.thisworks.setText("Connection_Successful")
    self.connectionStat.setText("Communications_are_active")

def axisSettings(self):
    cont = PS4()
    #Input boxes when "Update Axis" is clicked
    text, ok = QtWidgets.QInputDialog.getText(self, 'Axis_Value[0]', 'No_Spaces')
    text1, ok = QtWidgets.QInputDialog.getText(self, 'Axis_Value[1]', 'No_Spaces')
    text2, ok = QtWidgets.QInputDialog.getText(self, 'Axis_Value[2]', 'No_Spaces')
    text3, ok = QtWidgets.QInputDialog.getText(self, 'Axis_Value[3]', 'No_Spaces')
    axis = [int(text), int(text1), int(text2), int(text3)] # Make an array of the values from the input dialogs
    self.axisVal.setText(str(axis))
    cont.axis_order = axis # Set the axis order for the controller equal to the new settings

def display(self, i):
    self.home.setCurrentIndex(i)

def hostSettings(self):
    #Input box when "Update Host" is clicked
    text, ok = QtWidgets.QInputDialog.getText(self, 'Host', 'Host_name_or_IP_address')
    newHost = str(text)
    if newHost == '':
        self.hostVal.setText(self.getHost)
    else:
        self.hostVal.setText(newHost)
    return newHost

def portSettings(self):
    #Input box when "Update Port" is clicked
    text, ok = QtWidgets.QInputDialog.getText(self, 'Port', 'Port_number')
    if ok:
        print('success')
        newPort = str(text)
        if newPort == '':
            self.portVal.setText(self.staticPort)
        else:
            self.portVal.setText(newPort)
    return int(newPort)

def connectController(self):
    new = PS4()
    cont.axis_order = self.axisSettings()
    print(str(cont.axis_order))
    new.listen() #Accept data from the manual controller, calls the listen definition from PS4Controller.py

def updateConnection(self):
    host1 = self.hostSettings()
    port1 = self.portSettings()
    s = socket.socket()
    status = s.connect_ex((host1, port1)) #Returns 0 if connect is successful, returns errno if not

    if status: #status = errno
        self.connectionStat.setText("Update_and_Connection_Unsuccessful")
        self.thisworks.setText("Update_and_Connection_Unsuccessful")
    else: #status = 0
        self.connectionStat.setText("Update_and_Connection_Successful")
        self.thisworks.setText("Update_and_Connection_Successful")

def liveData(self):
    graph_data = open('test.txt', 'r').read() # Open the text file to read in data
    lines = graph_data.split('\n') # Read in data from different lines
    xs = [] #Empty list
    ys = [] #Empty List
    for line in lines:
        if len(line)>1:
            x, y = line.split(',') #Read in data in the form of (x ,y)
            xs.append(int(x))
            ys.append(int(y))

```

```

    return xs,ys

def initplt(self):
    self.plotwidget = pg.PlotWidget() #Initiate the plotting widget field
    self.mplvl.addWidget(self.plotwidget) #Set the plotting widget field to populate the QVBoxLayout widget field
    self.plotwidget.setLabel('left', 'Altitude [m]') # Y-Axis name
    self.plotwidget.setLabel('bottom', 'Time[s]') #X-Axis name
    self.plotwidget.show()

def update1(self):
    #read in the data from the liveData definition in the form of two separate lists.
    #list1 = x-values, list2 = y-values
    list1 ,list2 = self.liveData()
    self.plotcurve.setData(list1 ,list2) # Plot the data

def move(self):
    self.t+=1 #Move the data 1 spot to the right
    self.update1() # Call update1 definition to get the new data

if __name__ == '__main__':
    app = QtWidgets.QApplication(sys.argv)
    main = GUI()
    main.show()
    QtWidgets.QApplication.processEvents()
    sys.exit(app.exec_())

```

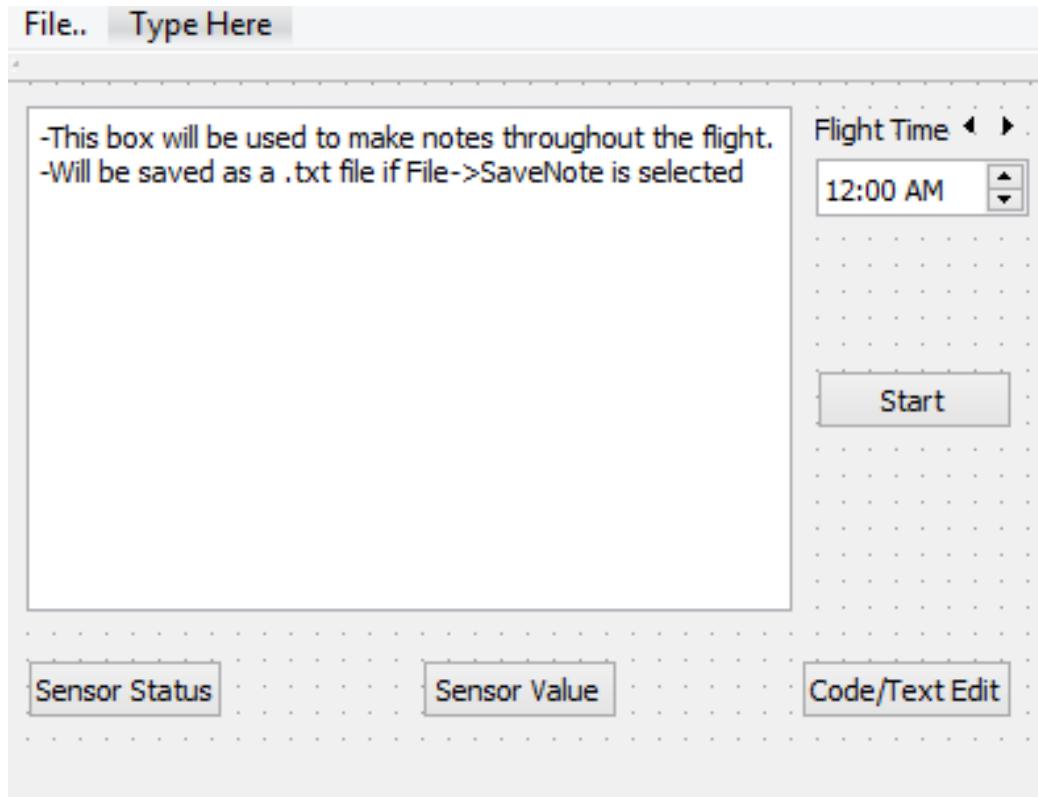


Figure D.1: Original GUI Prototype Home Page

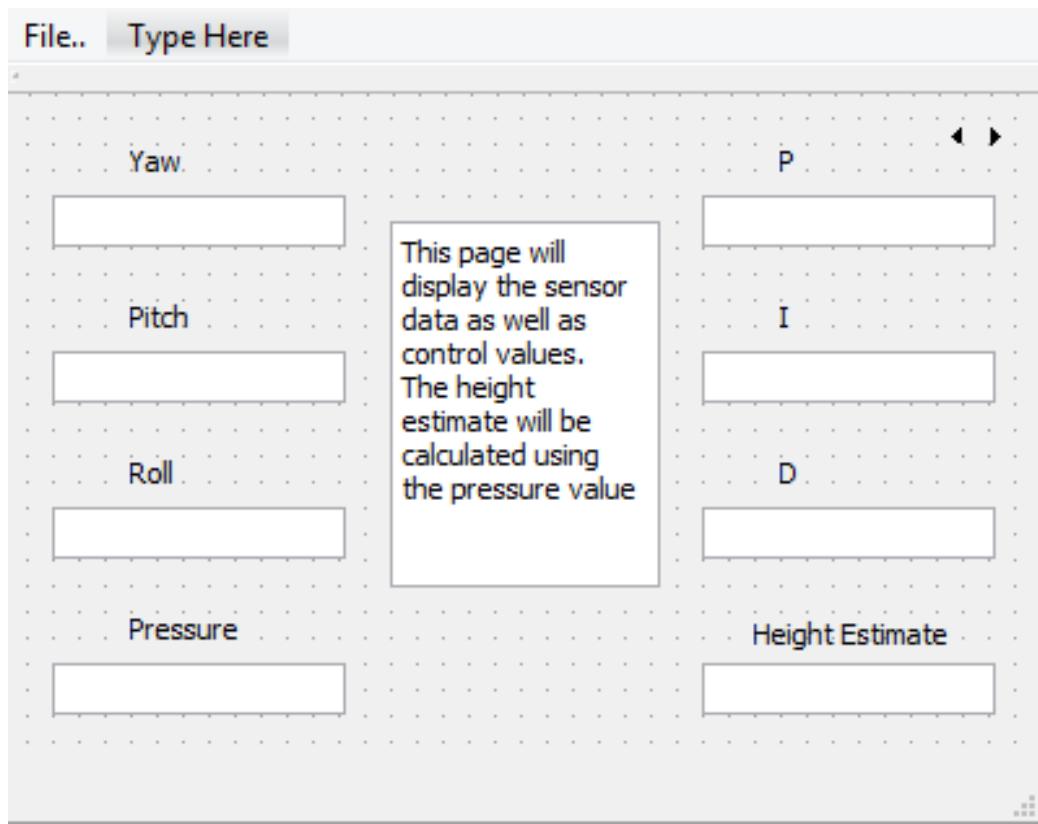


Figure D.2: Original GUI Prototype 2nd Page

E Gantt Charts

Appendix C: C1 Second Semester Gantt Chart

The Gantt chart illustrates the project timeline across several phases:

- Phase 1 (Initial Setup):** Tasks include Refine Physical Model, Controller Tuning, GUI Platform Evaluation (QT/TK), and Preliminary Communications implementation. These tasks are primarily completed by early January 2017.
- Phase 2 (Hardware Implementation):** Tasks like Raspberry Pi Implementation, Control Signal Relaying, Define Sensor Data Class, Determine Serialization Method, and Arduino Implementation (led by Lucas) begin in January and continue through February.
- Phase 3 (Software Development):** Tasks such as Sensor Querying, Speed Controller Initialization Sequence, Control Signal Reading/Testing, Controller Implementation, Plan Testing, and Base Station Development (led by Brendon) are scheduled for January and February.
- Phase 4 (Testing & Revision):** Platform Testing, Testing & Revision, and Revise Documentation are planned for late February and early March.
- Phase 5 (Finalization):** Prepare Final Presentation is the final task listed, scheduled for mid-March 2017.

Key milestones marked with downward-pointing arrows include the start of Raspberry Pi Implementation, the start of Arduino Implementation, the start of Base Station Development, and the completion of Testing & Revision.

Name	Work	Week 38, 2016					Week 39, 2016					Week 40, 2016					Week 41, 2016					Week 42, 2016					...								
		19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Research	15d																																		
RaspberryPi	5d																																		
Motor Driver/MCU	5d																																		
Simulation Research	5d																																		
Functional Breakdown	3d																																		
Simulation Design	134...																																		
Discrete Time Simulation Review	30d																																		
Hovering Simulation	10d																																		
Simulink Simulation	79d ...																																		
Review MIMO Design Method	30d																																		
Model Inputs	9d 6h																																		
Model Disturbances	9d 6h																																		
Flight Model	30d																																		
Macro Testing at SMU	15d																																		
Controller Model	10d																																		
Review Hardware Communication	5d																																		
Pilot Training	15d																																		

