Preliminary Proposal Report

1.1 Problem Definition

Our client, Honeywell Aerospace has invited us to participate in their first annual navigation challenge competition. In this navigation challenge, college students from all around Puerto Rico will compete representing their respective universities. The challenge consists of designing a UAV that must fly along a pre-determined flightpath and through established waypoints. Each team will be given a Honeywell Inertial Measurement Unit (IMU) which, along with the assistance of a Global Positioning System (GPS) will provide for the UAV the required navigation data necessary for autonomous flight.

This project is multidisciplinary and as part of its Electrical Engineering team our main task will be to design the UAV's control system to ensure proper maneuver for unforeseen disturbances. We will be taking into consideration the four elements which make up a control system: the sensor, the transmitter, the controller, and the final control element. Our sensor would be our IMU. Furthermore, we must identify the proper way of transmitting the information received from this sensor and thus, we must identify the proper filters to be implement as well. Additionally, the most effective controller (microprocessor) for our case must be identified. Finally, we must study how this microprocessor will be integrated with the final control element which would be our UAV's motors and propellors.

1.2 Introduction

The main idea behind a control system, which is to hold the values of controlled quantities constant or cause them to vary in a specific manner, has been implemented for thousands of years. The first recorded feedback controller device was the ancient water clock created around 270 B.C. This device kept time by regulating the water level in a vessel and, therefore, the water flow from that vessel. However, the theory behind these devices, Control Theory, was just recently developed. Its history may be divided into four main periods: the early control period (Pre-1900), the pre-classical period (1900-1940), the classical period (1935-1960), and the modern control period (Post-1955).

For the early control period, the most significant development was that of the steam engine governor. One of the first most recognized governors was the centrifugal fly-ball governor used to regulate the speed of steam engines by James Watt in 1788. Then, through James Clerk Maxwell (1831-1879) paper "On Governors" scientists were able to describe control systems mathematically. Edward J. Routh continued Maxwell's studies and developed what we now know as the Routh-Hurwitz stability criteria.

During the pre-classical period, a rapid and widespread applications for feedback controllers were observed. During this period the feedback amplifier was created by Harold Stephen Black. The lack of theoretical understanding for control system was reduced when Nicholas Minorsky (1885-1970) presented his analysis on position control systems and formulated a control law that we now refer to as three-term or PID control. Stephen Black and Harry Nyquist then laid out the foundations of the Nyquist analysis and published it in 1932 which led to a deeper understanding of the benefits of negative feedback in systems.

During the classical period, scientists started to represent and manipulate mechanical and electrical systems through block diagrams. Furthermore, in 1943, Albert C. Hall showed how blocks could be treated as transfer functions using the Laplace transform approach and how with this approach the Nyquist test for stability could be used. Additionally, this finding helped determine the gain and the phase margin for a control system and introduced the use of M and N circles that enabled the estimation of closed loop time domain behavior. By the end of the World War II, different design methodologies had been developed.

Finally, during the modern control period, the "state-space" approach was developed to express with more facility the differential equations that represented control systems. Then, during the 1950s. Kalman presented a paper, "On the General Theory of Control Systems," that clearly showed that a deep and exact duality existed between the problems of multivariable feedback control and multivariable feedback filtering, hence ushering in a new treatment of the optimal control problem. This led to the concept of "pole shifting" which greatly improved control systems. On the other hand, the creation of the Kalman-Bucy filter, demonstrated the basic role of feedback in filtering theory and the duality that existed between the multivariable control problem and multivariable feedback filtering. During this period, the use of parametric models in terms of state equations was made possible which led to parameter estimation and related techniques. In general, the study of controls has made possible a large number of advanced our society in a number of areas such as industrial processes, communications, and navigation.

If we continue on the subject of navigation which control theory has made possible one may arrive to the term “Drone”. This is a broad term that is used to describe any kind of unmanned aerial vehicle (UAV). As such, it can be used to describe both UAVs that are remotely controlled and those that are controlled by onboard computers. UAV’s can fly for long periods of time at a controlled level of speed and height and have a role in many aspects of aviation. UAVs were originally built for military purposes. Especially, as weapons in the form of aerial missiles guided by remote controls through radio waves. The first pilotless vehicles were built during the First World War. These early models were launched by catapult or flown using radio control. Shortly after, the U.S. Army built the UAV known as the Kettering Bug, intended to be used as “aerial torpedoes” using gyroscopic controls. In 1935 the British produced a number of UAVs controlled by radio to be used as targets for training purposes. These radio-controlled drones were also manufactured in the United States and used for target practice and training. After World War II drones began stepping up in their development for the traditional use of for target practice to real time surveillance, intelligence gathering and carrying weapons.

Drones have seen a rapid growth in consumer electronics with advances in technology. In 2010 with the advent of the smartphone, the consumer drones took off and were mainly designed to capture aerial photography. GPS, processors, cameras, and gyroscopes were some of the equipment that became suitable for use on drones after their use in smartphones. Today, drones have found wide range of applications for the civil use in the form of small quadcopters and octocopters. These are used today for wide range of functions such as search and rescue, surveillance, traffic monitoring, weather monitoring and firefighting to personal drones and business drone-based photography, as well as videography, agriculture and even delivery services.

In the present time, many companies have involved themselves in the design and development of drones and their components. Honeywell is one of these companies. It was initially founded in 1906 by Mark C. Honeywell in Wabash, Indiana. The headquarters of the company are located in Morris Plains, New Jersey. It is a multinational company that makes a variety of commercial and consumer products, engineering services and aerospace systems for private consumers to major corporations and governments. Its first business venture was the Thermostat heating control. During World War II, Honeywell had a role by manufacturing cluster bombs and missile guidance systems. In the 1950s, developed the "Automatic Master Sequence Selector" which was an automatic control system for airplanes and in the 1960s, entered the computing business, developing computers and Operating Systems among other business. Through the years, the company saw a large number of businesses, acquisitions and made massive expansions and diversifications but aligned with the existing technologies of the company.

In Puerto Rico, Honeywell has a sub-division called Honeywell Aerospace. The first facility was placed in Aguadilla and is currently a key service center supporting aerospace operations and customers throughout the Americas. From another point of view, Honeywell has been known for promoting professional development in students through competitions. Up to this date they have sponsored three competitions in Puerto Rico. One of there most recent competitions is the Honeywell Puerto Rico Navigation Challenge in which students are given the opportunity to design, develop, and manufacture an Unmanned Aerial Vehicle (UAV) using one of Honeywell’s products to provide the necessary navigation data. For our capstone project we will be participating in this competition to work on the design for the UAV’s control system.

1.3 Objectives

This capstone project has the following objectives:

- Design and develop a flight control system for an Unmanned Aerial Vehicle (UAV) to fly autonomously and manufactured by the students of the PUPR.
- Make use of the Nasa Systems Engineering Handbook to comply with competition requirements.
- Apply the engineering concepts and methodologies learned along with industry design review process to experience real world of aerospace product design.
- Integrate navigation equipment provided by Honeywell in the UAV design.
- Understand the operation and functionality of the equipment provided by Honeywell.
- Research on the different types of filters to be implemented to ensure that information from the navigation system is properly received.
- Identify the different types of disturbances that the UAV could be exposed to define the critical variables needed for the control algorithms.
- Design control algorithms in order for the octocopter to be able to execute required tasks.
- Design a controller to interface with the navigation equipment provided by Honeywell.
- Research on UAV octocopter systems and how to model and simulate them.
- Design a Matlab/Simulink model for UAV and control system.
- Submit the final project documentation.
- Perform the final project presentation.

1.4 Realistic Constraints

Students:

- Some of the students in the multidisciplinary competition team are not enrolled in Capstone course. Therefore, there is a risk that they might not be fully committed and thus, we have the challenge of motivating them to execute their tasks efficiently and effectively.
- Lack of knowledge about the process and complexity that the design and manufacture of a UAV from scratch entails.

Limited Budget:

- Honeywell provided an initial budget of $2,000. However, the total cost of the project will depend on the hardware and software tools to be used; therefore, the request for additional equipment must be approved by PUPR.

Reliability:

- Mission time is less than 15 minutes; the speed at which the drone will behave depends on key components integration, the database and programming language used as well. Communication with the host machine for data from the drone sensors is critical as well as the drone components and sensors sending the data to the host machine.
- The rechargeable battery should support UAV for an average flight of 15 minutes
- That the drone will function as required by having stable flight, safety controls, and a resistance to impact collisions.

Third Party:

- The timeline of the competition project is 10 months and Capstone requirement is 6 months meaning that there might be new team members to continue the project
- The flying coordinates will be provided the day of the competition by Honeywell and they are subject to change.

Safety and Health:

- The safety of the users and others around the drone is paramount. The drone design needs to meet the performance specifications as indicated in the competition rules and objectives previously stated.
- The flight controller system should be able to handle loss of communication and return to point of origin until it establishes communication again.

Timing and Logistics:

- Most of the equipment components need to be purchased and delivered.
- Timely installation and integration of all components needed as designed to perform the required tests.
- Compliance with Honeywell deadlines deliverables

1.5 Multidisciplinary Aspects

The design, development, and manufacture of a UAV is supported by the study area of mechatronics. This area involves three engineering disciplines: mechanical engineering, computer engineering, and electrical engineering. This project also requires the use of systems engineering to properly identify and structure the UAV system to be designed. Additionally, the implementation of systems engineering will ensure adequate project progression. The following points will briefly specify the role for each of the mentioned disciplines:

Systems Engineering:
This area of study is necessary due to Honeywell's requirement to present project progress according to the NASA Systems Engineering Handbook (NASA/SP-2007-6105, Rev1).

Mechanical Engineering:
This area of study is necessary to create the UAV's frame and to execute the analysis of the mass and structure of the UAV with its selected mechanical and structural components. Students from PUPR´s department of mechanical engineering will be working in this area.

Computer Engineering:
This area of study is necessary to develop software through which the UAV's missions will be entered and stored. Users should also be able to monitor mission progress through this software. The program to be written should ensure the following:

- Air vehicle take off and landing
- Path-calculation

Electrical Engineering:
This area of study involves multiple sub-disciplines in electrical engineering which are controls, power, electronics, and communications. The following points describe the application of each sub-discipline:

- Controls: Design the UAV's control system to stabilize its movement toward waypoints.
- Power: Execute load analysis on the UAV system.
- Electronics: Evaluate electronic components to be added such as MOSFETs (to control direction of propellors) or capacitors (to avoid power surges).
- Communications: Establish communication link between UAV, ground control station, and radio controller.

Test Engineering:
This area of study is necessary to be able to properly assess the performance for each selected UAV component and evaluate the designed UAV system after integrating developed software with hardware.

Software:
The design of the UAV will require the use of the following software:

- SolidWorks
- Matlab and Simulink
- Python programming in Linux

1.6 Procedures

I. Research on quadcopter UAV
   A. Classifications
   B. General structure
   C. Multi-rotor aerodynamics
II. Research on UAV components
   A. Navigation modules
      1. IMU
         - Gyroscope
         - Accelerometer
      2. GPS
   B. Ultra-sonic sensor
   C. Receivers
      1. Function
      2. Filtering received data
   D. Microprocessors
   E. Transmitters
   F. Propellers
   G. Power distribution board
   H. Electronics speed controllers
   I. Motors
   J. Battery
      1. Battery management function
      2. Voltage monitor
   K. Additional electrical components
      1. MOSFET
      2. Capacitors
      3. Resistors
III. Research on UAV ground control station
   A. Function
   B. Components
IV. Research on UAV control systems
   A. Control methods
V. Research on UAV modeling
   A. Inputs and outputs (Critical variables)
   B. Basic aerodynamic equations
   C. Disturbances
   D. Simulink
VI. Research on UAV simulation and hardware integration
VII. Attend multidisciplinary team reunions
VIII. Attend meetings at Honeywell facilities
IX. Write documentation containing official research review
X. Identify components to be bought
XI. Develop control algorithm and implement in Matlab.
XII. Perform 1st presentation for Capstone I

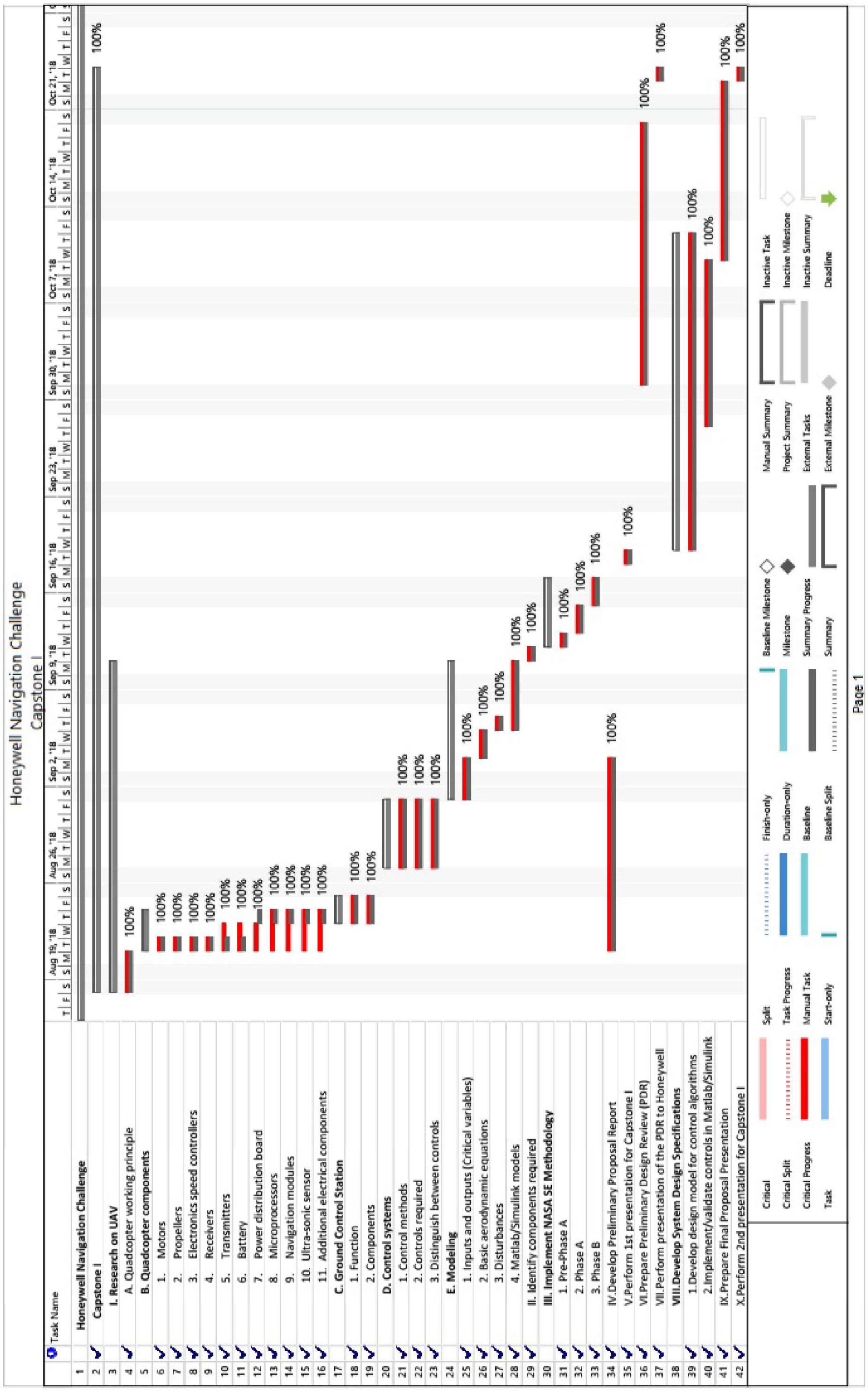
XIII. Perform 2nd presentation for Capstone I
XIV. Test Modeled UAV (Simulate) and evaluate control system
XV. Integrate designed control system in hardware
   A. Identify the transmitter to be used to pass information from air vehicle to ground control station
   B. Identify the receiver to be used to receive information from the IMU and the ground control station
   C. Transfer Matlab code into C code (subject to change) for integration on microprocessor
XVI. Implement and test control system
XVII. Complete deliverables for Honeywell
XVIII. Perform 3rd presentation in Capstone II
XIX. Write and prepare final presentation
XX. Perform final presentation in Capstone II

1.7 Expected Results

Once we finish our Capstone Project, we expect to have the following results:

- Acquire knowledge concerning the design process in system engineering
- Acquire knowledge concerning the design of a UAV
- Acquire knowledge concerning the most effective control methods for UAVs
- Acquire knowledge concerning the topic of signal filtering
- Develop a model for the UAV to be manufactured including possible disturbances
- Achieve simulation of the UAV and verify proper design
- Identify the UAV's electrical components
- Identify the UAV's power demand
- Establish a communication system between user and UAV
- Successfully design and manufacture a UAV that flies through specified waypoints
- Integrate the navigation equipment provided by Honeywell on the designed UAV
- Comply with the competition requirements set by Honeywell

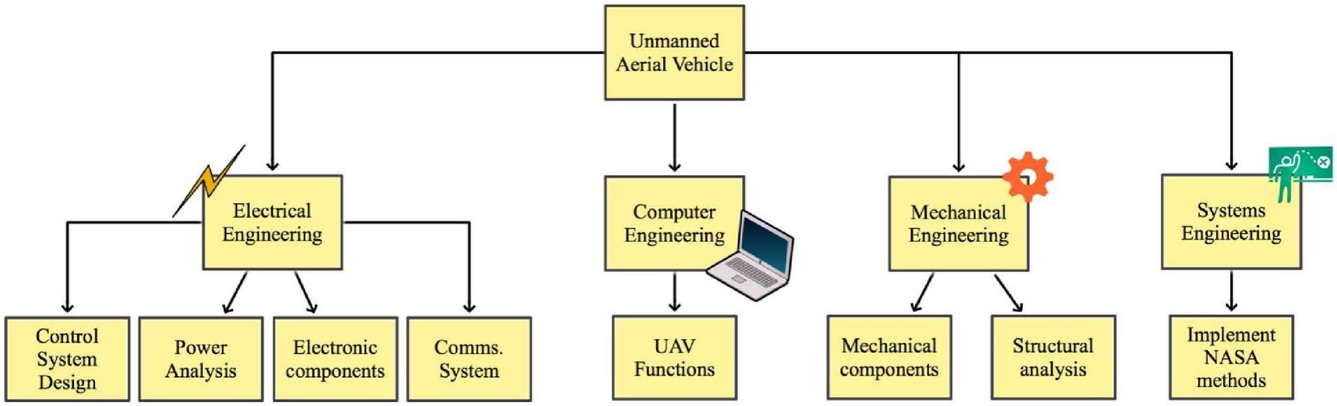
1.8 Work Schedule



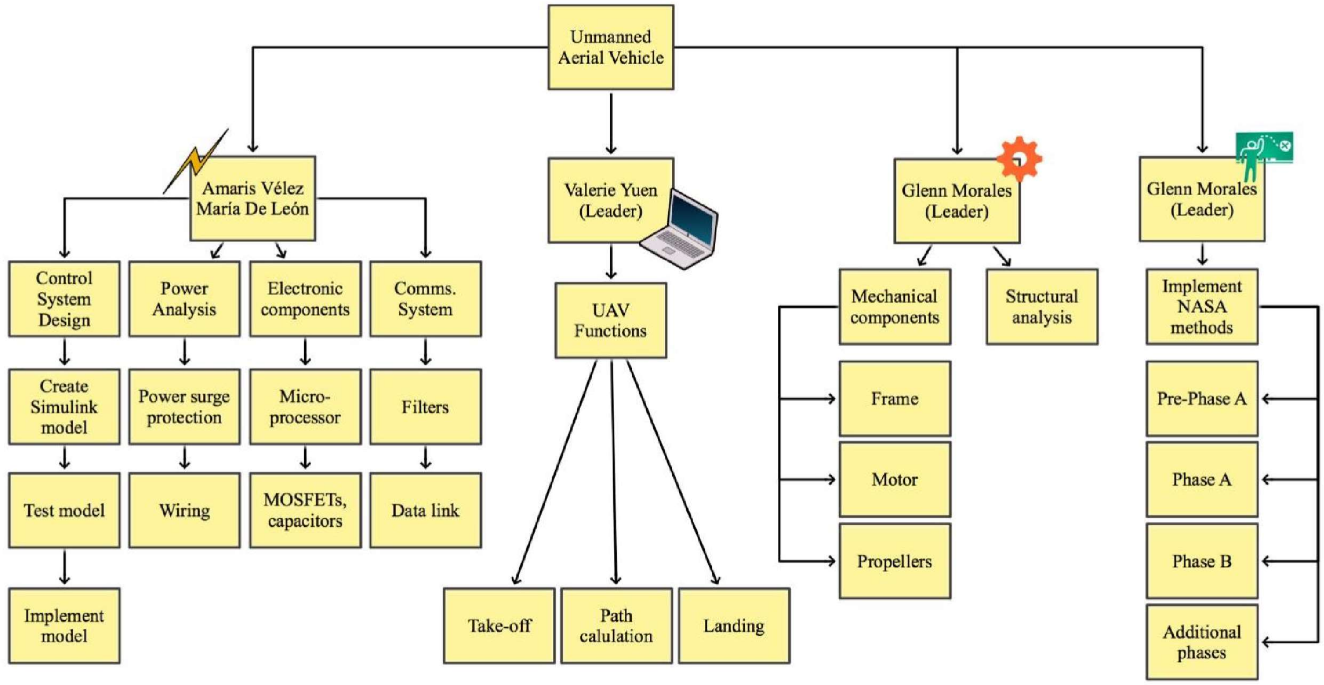
1.9 Budget

Item	Quantity	Group	Honeywell	P.U.P.R.	Total
Initial funding	1		$2,000.00		$2,000.00
Professional Services	2	$12,000.00			$24,000.00
Transportation (provided)	1			$0.00	$0.00
Gyroscope, Accelerometer & GNSS	1		$20,000.00		$20,000.00
RC Transmitter	1			$150.00	$150.00
RF Transceiver	2			$50.00	$100.00
Motors	8			$30.00	$240.00
Electronic Speed Controller	8			$18.00	$144.00
Barometric Pressure/Temperature/ Altitude Sensor	1			$10.00	$10.00
Cables (Multi-stranded wires, Silicone insulated)	1			$20.00	$20.00
Arduino Microcontroller	1			$22.00	$22.00
Arrieta G25 Microcontroller	1			$35.00	$35.00
Power Supply (LiPo Battery)	1			$120.00	$120.00
Power Distribution Board	1			$30.00	$30.00
Voltage Regulators	4			$10.00	$40.00
Project Plan software license	1	$79.00			$79.00
Shipping cost					$150.00
Taxes					$0.00
	Total	**$12,079.00**	**$22,000.00**	**$495.00**	**$47,140.00**

1.10 System Block Diagram

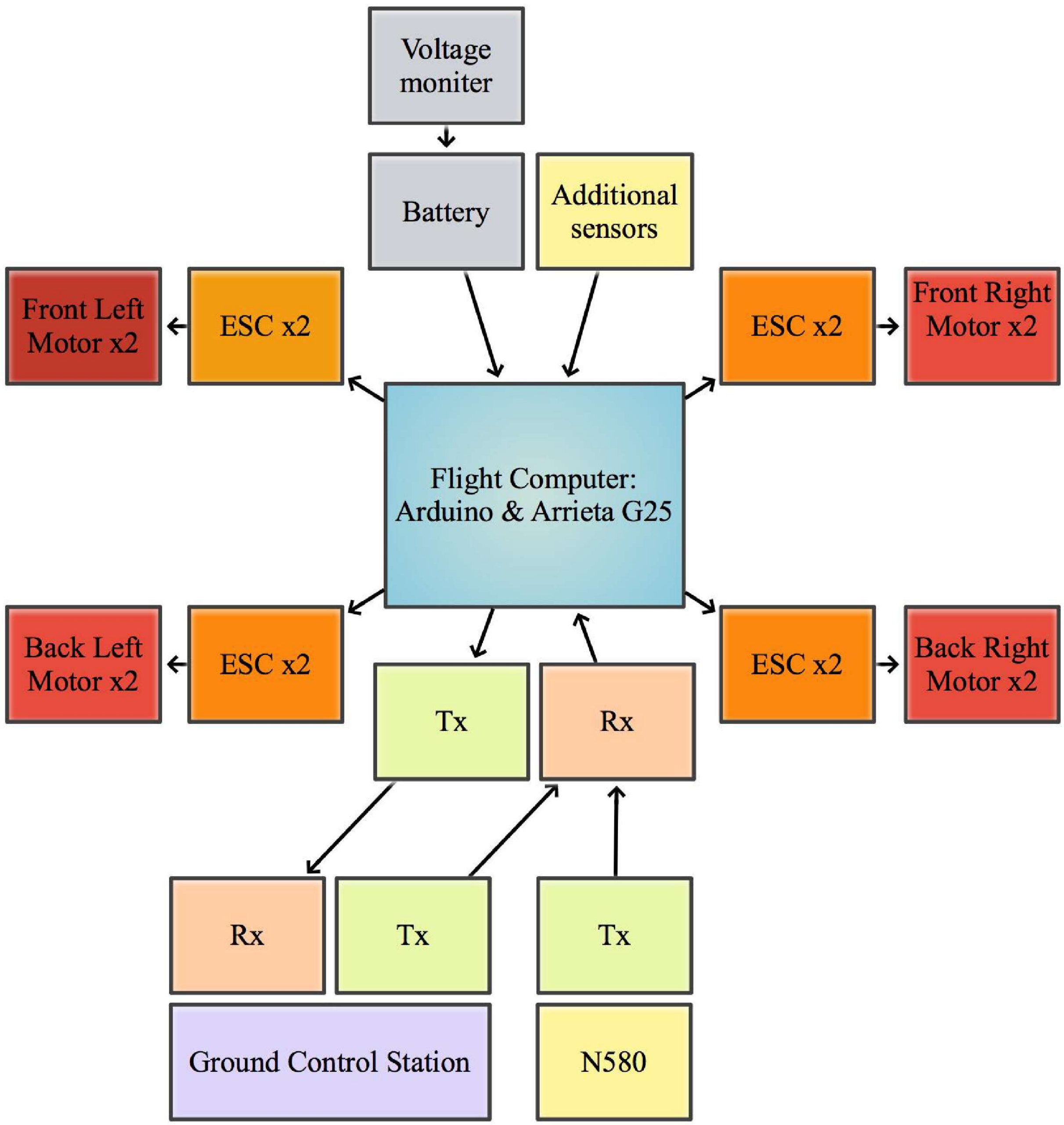


1.11 Interface Sub-System Architecture



Final Proposal Report

2.1 Sub-System Component Specification



2.2 Design specifications

Component	Power Requirement	Weight	Dimensions	Matlab/Simulink Integrable	Verification Method
N580 Gyroscope, Accelerometer & GNSS	8W (without Antenna)	430g	90 x 60 x 60 mm	N/A	Analysis
Arduino Nano	Operating Voltage (logic level): 5V Input Voltage: 6-20V	7g	43.18 x 18.54 mm	Yes	Test
Arrieta G25 Micro-controller	Operating Voltage (logic level): 5V	N/A	53 x 25 mm	Yes	Test
Power Supply	14.8V 7500mAh 4S Cell 75C-150C	622g	139.0 x 46.6 x 48.5 mm	N/A	Test
RC Transmitter	8ch, 2.4Ghz	N/A	N/A	N/A	Test
RF Transceiver	8ch, 2.4Ghz	N/A	N/A	N/A	Test

Motors	KV 740 rpm/V, 0.28 Amps @ 12 Volts	68.6g	63.5 x 53.3 x 35.5 mm	N/A	Test
Electronic Speed Controller	Input Voltage: 2-4S Lipo; Continue Current: 20-30A	30g	74 x 32 x 10 mm	N/A	Test
Barometric Pressure/Temperature/ Altitude Sensor	3 to 5VDC, 3-3.5 voltage regulator	1.2g	18 x 19 x 2 mm	N/A	Test
Power Distribution Board	12V and 5V outputs	13g	36 x 50 x 8 mm	N/A	Test
Voltage Regulators	Constant 5V or 12V	0.5g	13 x10 x 3 mm	N/A	Test
Cables (Multi-stranded wires,Silicone insulated)	10AWG (140A) -20 AWG (13.87A)	N/A	N/A	N/A	Inspection

The UAV will include brushless DC motors that runs on DC electric power supplied by a battery in order to convert the electrical energy into mechanical torque. The advantages of brushless DC motors are and not limited to a very precise speed control, high efficiency, high reliability, reduced noise, longer lifetime (no brush abrasion) and no ionizing sparks. According to the selected motors, the electronic speed controllers (ESCs) are then selected which receives input from the controller to be designed and transfers this signal to the motors.

Figure 1: Cobra Motor

Figure 2: Electronics Speed Controller

The UAV will operate with a 7,500 mAh 4S Lithium Polymer (Li-Po) battery. Lithium Polymer batteries has the advantage of lighter weight, higher capacity and higher discharge rate compared with other batteries like Lithium-ion. Each motor will be connected to an Electronic Speed Control in order to efficiently control the speed of an electric motor and its direction.

Figure 2: LiPo Vant Battery

Our UAV will have a flight control system that will consist of: an Arduino board, a micro-controller and navigation system that with the feed of sensors and a radio control will directly control the flying device in real time. The Arduino board is an open-source electronic platform that is able to read inputs from the ESCs sensors and turn it to output. The Arietta board is a multi-chip module microprocessor is capable of doing multiple tasks at a time and has larger memory than Arduino. It is important to mention that the Arduino Nano has a clock speed of 16 MHz and the Arietta has a clock speed of 400 MHz.

Figure 3: Arduino Nano

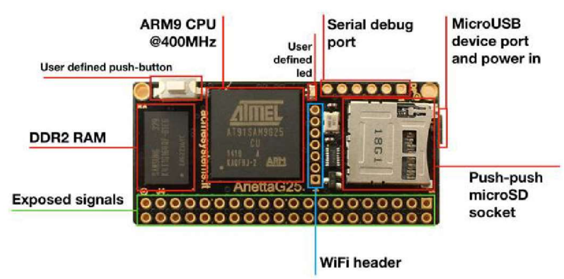


Figure 4: Arrieta G25

The UAV software will be designed to tell the UAV where to go and what to do while flying from A to B. In order to understand and connect all necessary information of the UAV, the software installed to control the flight patterns, altitude and other important information for UAV to work and act accurately. The Radio Control (RC) Receivers and Radio Frequency (RF) Transmitter will enable the transmission of data needed for flight to proceed. Radio signal can be transmitted from a ground control remote system.

The navigation system, provided by Honeywell, consists of an integrated GPS and an Inertial Measurement Unit to provide position, velocity, angular rate, linear acceleration, roll, pitch and heading information. Additionally, a barometric/temperature/altitude sensor will provide temperature, pressure and altitude data.

Figure 7: N580 navigator provided by Honeywell

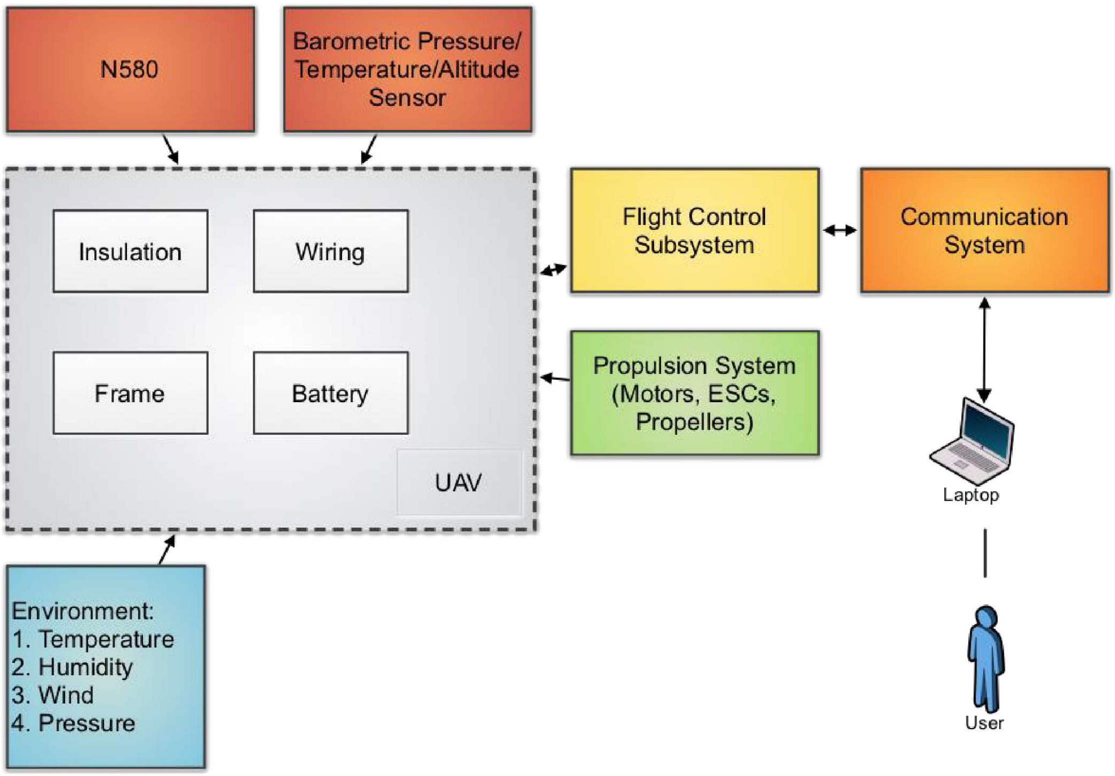
The navigation control system will operate alongside the attitude control system. The attitude control will be done using a PID (Proportional Integral Derivative) feedback controllers for each Axis, a Fuzzy control and a Kalman filter. The compensated output of the PID controller will be processed by the MCU and the respective signals are sent to the ESC and motors. Uninterrupted flight will be enabled with the implementation of a state machine in the MCU and the implementation of the Attitude control system leading the drone on its way and giving the information where to go and when to react. In the event of a failure, it will switch to manual so the control the radio sticks provide reference signals to land the octocopter in a safe controlled manner. The Kalman filter is an optimal estimator; it takes in information which is known to have some error, uncertainty, or noise. For example, a octocopter pointing in one direction while flying/moving in another direction. The goal of the filter is to take in this imperfect information, sort out the useful parts of interest, and to reduce the uncertainty or noise.

The control system for the UAV will be first model in Matlab/Simulink to control the octocopter in a virtual simulation environment and then the code will be uploaded into the MCU. Simulink provides enhanced capabilities and features for the control design for aerospace vehicles and robots. There are built-in blocks available which were used directly by setting the data in the respective blocks to our specifications, and then used for analyzing the output. A mathematical model for the controlling the octocopter in simulations will be designed using the final selected component information. Then the PID & Fuzzy control techniques will be used to model the control setup for the octocopter altitude and motion controls.

2.3 Drawings

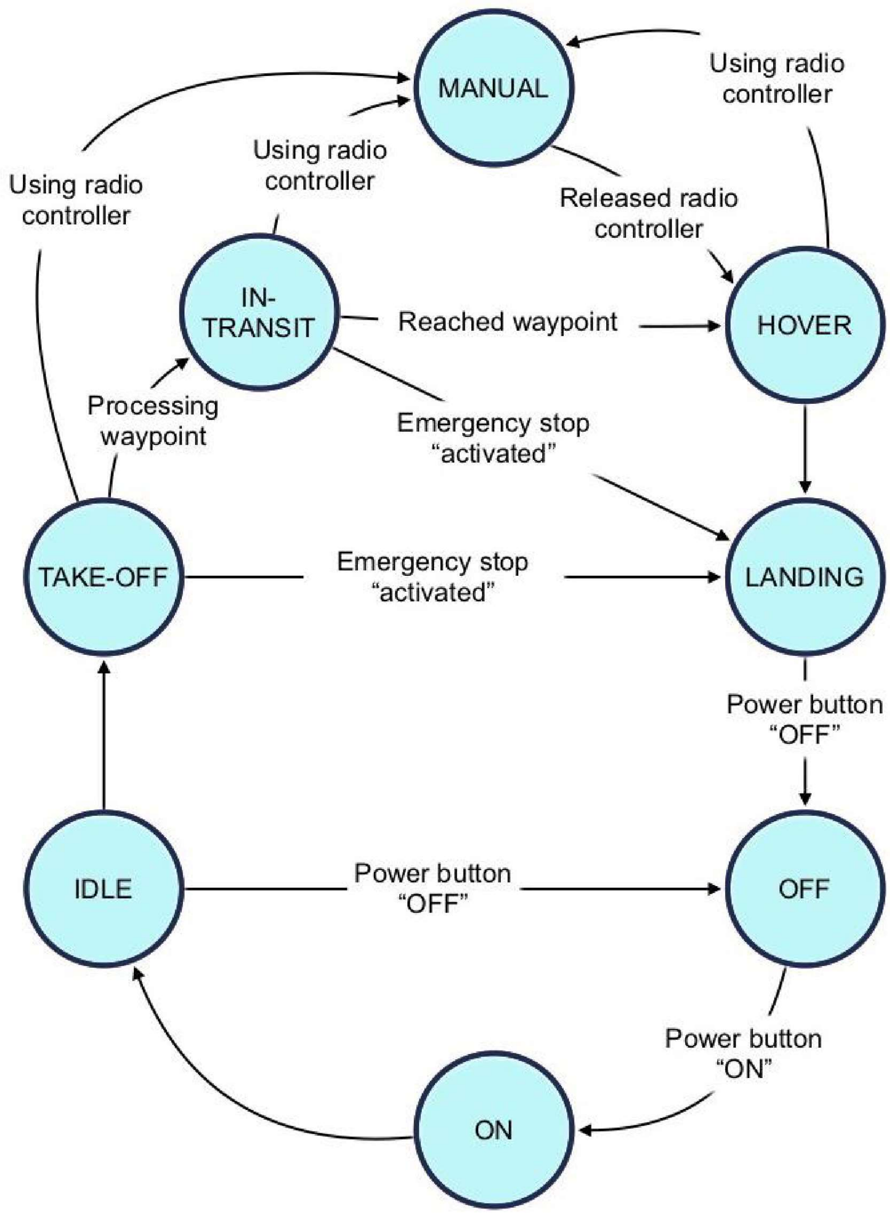
System Boundary Diagram

The following diagram represents the different system with which the UAV will interact or contain. Here it is shown how the user will have a graphical interface which will be connected to the UAV´s communication system and from this system the necessary input data reaches the control system which decides how the UAV will operate through its propulsion system according to user input.



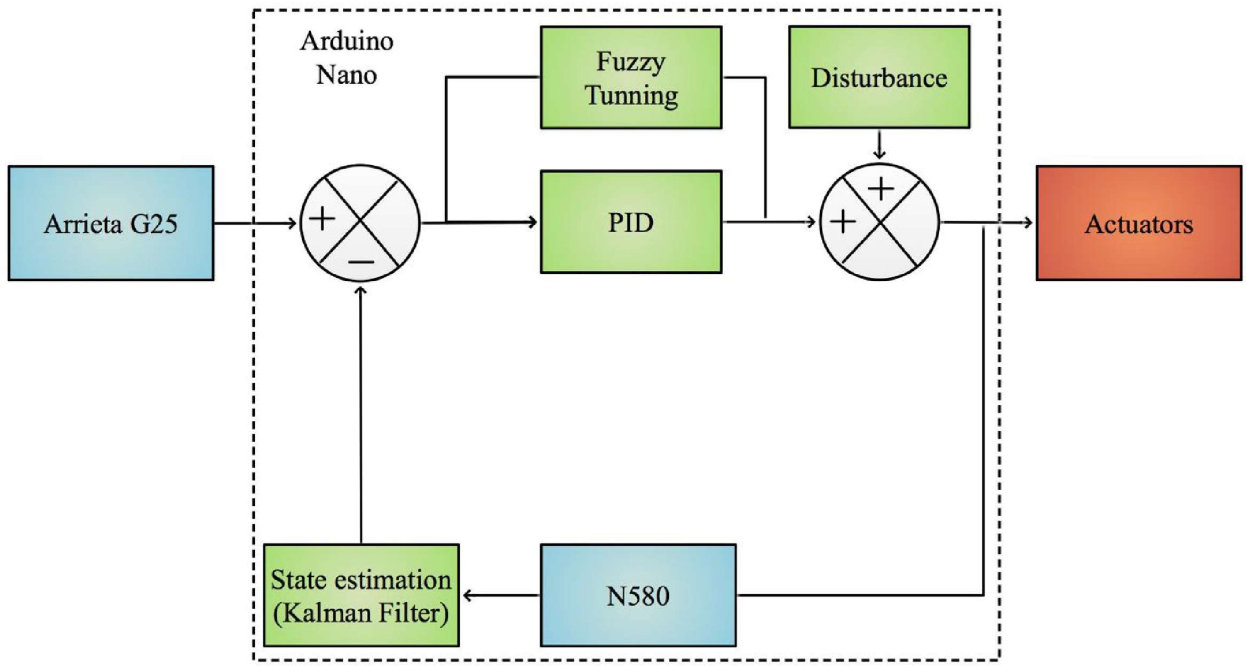
Mode Transition Diagram

This diagram represents the different modes of operation the UAV should have according to the client's requirements. The different mode of operation as seen in the diagram below are: On, off, take-off, landing, manual, and hover.



Block Diagram

The following block diagram represent a concept of how the control system will be modeled in Simulink and then embedded on the Arduino Nano development board.



2.4 Schematics

Solid Works Model (Given by Mechanical Engineering Team)

Preliminary Circuit Schematic