UAV Avoidance System

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San Luis Obispo

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Abstract:

This is an ongoing design project being funded by Northrop Grumman in which Cal Poly SLO is working in collaboration with Cal Poly Pomona to complete a working design at the end of each academic school year. The project consists of two UAVs that can navigate around a given area without running into each other or other obstacles. There are sensors to be mounted on the vehicles that can detect objects within a given distance and a microcontroller is used to control how the vehicle responds to an object being detected. The avoidance code has been written for previous years' designs but improvements are to be made to improve the speed and accuracy of the current code. The UAVs should be able to communicate wirelessly with a nearby ground station so they may be controlled during flight. The previous years' communication system high level diagram is shown below in Figure 1. When needed, an autopilot is to be implemented that can still avoid objects as it flies around. Additionally there needs to be security in the communication system to ensure interference is eliminated. In the past GPS was allowed to be used to track where the vehicles were in space, however, this year a communication system must be implemented that can operate in an area in which GPS is not available. A simulator is to be implemented that can test how the avoidance system works on the computer before testing it with UAVs.

Chapter 1: Introduction

The purpose of this project is for Northrop Grumman to give college students a challenging design problem to see how they handle it. The overall goal is to create a working system on two UAVs that can detect and avoid obstacles as they fly around. Each year various students work on this project and demo a working design at the end of spring quarter. Additionally every year extra design features are added or changed from the previous year to make the overall product better. The differences in last years' project and this years' project is shown in table 1 below. There are two main goals of this year is to improve over last.

1. The collision avoidance algorithm needs improvement so obstacles can be avoided at an earlier time and a new flight path is determined more quickly.

2. The entire system should be able to work without the use of GPS. In past years GPS was used for determining position of the aircrafts while communicating with the ground station. This year radar is being looked into for positioning purposes.

The electrical engineering portion of this project will incorporate a wireless communication system that can communicate the two UAV's with the ground station. To summarize both UAV's must be able to communicate with each other as well as the ground station at the same time with no interference. The ground station will simply have a receiver but the UAV's must contain a transmitter and receiver. The data rate will be very slow in the kilo bytes per second range but must be very efficient. In the previous year the team had trouble with getting the two UAV signals to not interfere with each other when sending a signal at the same time. The figure for the high level diagram of the communication system is shown below in Figure 1. Additionally the UAV's used Xbee's to communicate at 900MHz but the data rate that was listed on datasheet for the devices could not be achieved by the team. Therefore there may have been setup errors incorporated with the final system. The Cal Poly Pomona team is additionally working on different components of the same project and will be put together at the end of the year.

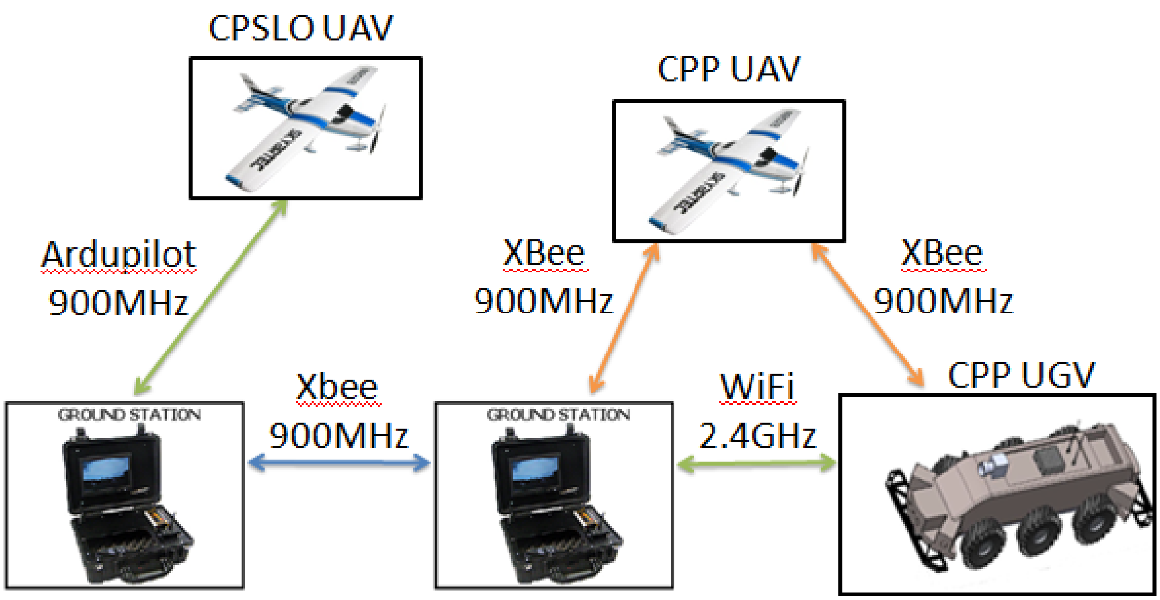

Figure 1: 2013 Implemented Communication System

In figure 1 shown above is the completed communication system for the 2013 design done last year. The UAV's would communicate to two different ground stations, both at 900MHz. The Pomona UAV would communicate to a UGV also at 900MHz. The ground stations would communicate position to the UGV at 2.4GHz and at 900MHz

for the Cal Poly ground station. The problem that the group had last year was not getting the Xbees to communicate at the same time without interference. The communication devices need to be able to communicate with the other UAV as well as the ground station at the same time that the other UAV is also sending data. Therefore there will be a receiver and transmitter on each UAV as well as a receiver at the ground station. The Xbees transmit data at a random time but on average at a fast rate. Therefore very often the devices will be transmitting at the same time.

Table 1
Goals of Previous Year Vs Current Year Project

Project Specification	2013-2014 Project	2014-2015 Project
Position detection of UAV's	GPS used to determine location of UAV's	Radar/ultrasonic sensors
Communication Devices	900MHz Xbee's mounted on both UAV's and receiver at ground station	Two different sets of Xbee's operating at 900MHz and 2.4GHz so both UAV's may operate at the same time
Payload Delivery	Pinpoint a location using GPS for the UAV's to deliver a payload to	There will be no payload delivery .

Market Research

The market for this project is defense as it is the focus of the sponsor company Northrop Grumman. The defense market expands to approximately 130 companies around the United States that support the government and needs of national security. I am interested in this market because of the large scale applications that come with the projects being made at these companies such as radar systems, unmanned vehicles, and satellites.

This market is capable of a designing various projects that are needed by the government and country for reasons of national security. Defense companies specialize in various projects such as unmanned systems that can provide coverage of given areas without the need of a pilot. They design vehicles with various weapon systems integrated onto them that can operate on water, air, and land. Sensors are implemented into various systems so awareness is available even when an individual is unaware of surroundings. Overall the companies are capable of providing technologies and innovations provide safety to the military and citizens of the United States.

As stated above, the goals of these companies are to provide as safe an

environment as possible for the military and citizens of the United States. The technologies they create must be able to work as efficiently as possible and over a long period of time.

1. **Companies/Organizations**

Table 2
United States Defense Companies

Companies	Specializations
Northrop Grumman	Navigation Systems, Missile Defense, Military Aviation, Manned Aircraft, Unmanned Aircraft, optical sensors and weapons.
Bae Systems	Cyber and Intelligence, Electronics and Systems Integration, Military and Technical Services
General Atomics	Unmanned Aircraft Systems and Sensors, Transportation, Weapons and Support Systems, Aircraft Recovery Systems
Raytheon	Computer Intelligence, Missile Defense, Electronic Warfare, Precision Weapons

2. **Market Size**

   The size of this market extends to over 130 companies throughout the United States. The budget of the defense industry in the United States was 683 billion in the most recent years. Because of this large funding, many companies can thrive and continue to hire more employees and expand their business. The larger companies such as the ones listed above also have various companies that work for them so they can receive and give work for many people. Additionally the larger companies usually encompass most or all aspects of the defense market such as missile defense, ground vehicles, naval systems, radar systems, aircrafts, and guided weapons.

3. **Part of market addressable to my group:**

   Our project is addressable to the unmanned aircraft market. Many defense companies are working to create the most efficient forms of unmanned aircrafts so the use of a pilot is unnecessary. This makes it

safer for the people of the military who would have to put themselves in dangerous situations without this technology. This market must innovate safe vehicles that can perform efficiently from distances of thousands of miles without any issues or interference or hacking.

4. **Key areas of strength:**

Northrop Grumman specializes in large scale defense technologies to be used by the United States military and government. Because they are largely funded they can leverage very expensive innovations that many other companies cannot. The company has various sectors that it specializes in including aerospace systems, electronic systems, and information systems. One area of strength also includes having a broad range of projects that the company works on so they have a very large output of innovations.

5. **Window of opportunity for this market:**

The collision avoidance design is an ongoing project being incorporated by defense companies all around the country, a few examples are listed below.

1. The Navy chose a company called RDRtec to design a collision avoidance system onto two of their UAV's (Tritron and Fire Scout). The company was given a 3 million dollar contract to incorporate a radar based collision avoidance system with maximum efficiency.
2. General Atomics began developing a sense and avoid system in 2013 on board an unmanned air vehicle called "Triton" under a 10 million dollar military contract.
3. Northrop Grumman was given a 25 million dollar contract to incorporate a sense and avoid system on the BAMS maritime surveillance UAV in 2011 which was finished in late 2012.

6. **Investment to enter this market:**

Entering this market would most likely take a multimillion dollar military or government contract. The projects one would work on would not be made for the commercial market but for government of military use. The cost of materials can vary greatly from company to company and would be difficult to calculate. The cost of hiring an average engineer is about 95 to 100 thousand dollars when including all positions from entry level to upper management.

7. **Key partners needed to engage for success:**
   The key partners within the defense department would include all the big defense companies as listed above such as Lockheed Martin, Raytheon, and General Dynamics. These companies not only work on the large scale projects for the government but additionally employ and fund smaller companies to work in collaboration with them. Therefore success can be achieved by reaching out to these larger companies because of all the networking that exists within the defense market.

8. **Is the existing sales organization capable of selling into this market:**
   The existing sales organization is capable of selling into this market because these companies have already been established. Since this project is funded by a large company there already is the sales organization that exists and therefore it is obvious they sell into the market.

9. **Key potential customers:**
   As a defense company the key customers are the United States government and military. The military is the main customer in that they are responsible for national defense and the defense companies are responsible for the technologies being used by the military. The innovations being created by these defense companies often serve to keep the men and women in the military as safe as possible. The use of unmanned aircrafts is one example so no harm can come to anyone since no pilot would be needed. There would not be a lead customer to work with because the projects are mostly being funded and used by the United States government.

Product Description

Table 3
System Requirements

Marketing Requirements	Engineering Specifications	Justification
3.	Range of one mile between the UAV and the ground station	The distance that the transmitter can send a signal should not be too far as to cause any disturbances or interference

3.	Operate at a frequency of 900MHz and 2.4GHz	Different frequency signals are present in any flight space we select and therefore to avoid interference a specific frequency must be chosen
5.	Operate without the use of GPS	In real world applications the UAV's will not always be operating in a location that has GPS available
1.	Maximum of ten thousand dollar budget for all components	Northrop Grumman is giving a maximum budget to fund the project as it is a determined low cost for the given project
2, 4	UAV's should be able to perform a test flight for at least one hour	The UAV's goal is to provide coverage over a given area which can require long amounts of flight time
6	Detect and avoid obstacles from a certain detection distance	All flight vehicles travel at a minimum speed with a minimum turning radius, so it is necessary that the UAVs react to a nearby object once a certain distance away
5	Provide on board computer security so nothing can interfere or take control of the UAV's	In real world applications the UAV's are used for defense purposes so it is vital to ensure no hacking or interfering can take place
Marketing Requirements 1. Low Price (10000 dollar budget max for all devices) 2. Low Weight 3. Operates within one mile of ground station 4. Low Power 5. Communicate with other UAV and ground station simultaneously 6. Fast reaction time		

Table 4
TX and RX Module Requirements

Marketing Requirements	Engineering Specifications
Low Bit Error	Use digital modulation technique (either BPSK or QASK) that has lowest bit error rate for specific signal to noise ratio
Low Bit Error	Incorporate an antenna with gain of at least 2.5dB to maximize signal to noise ratio.
Transmitting and Receiving on both UAV's simultaneously	Incorporate two different transceivers that operate at different frequencies (900MHz and 2.4GHz) to avoid interference
Send data of at least 1.5k bytes per second	Use antenna that has a minimum bandwidth of 20MHz

System Requirements

The level zero black box diagram is shown below in Figure 2 and includes the inputs and outputs of the system. Table 2 explains the functions of each item listed in the black box diagram.

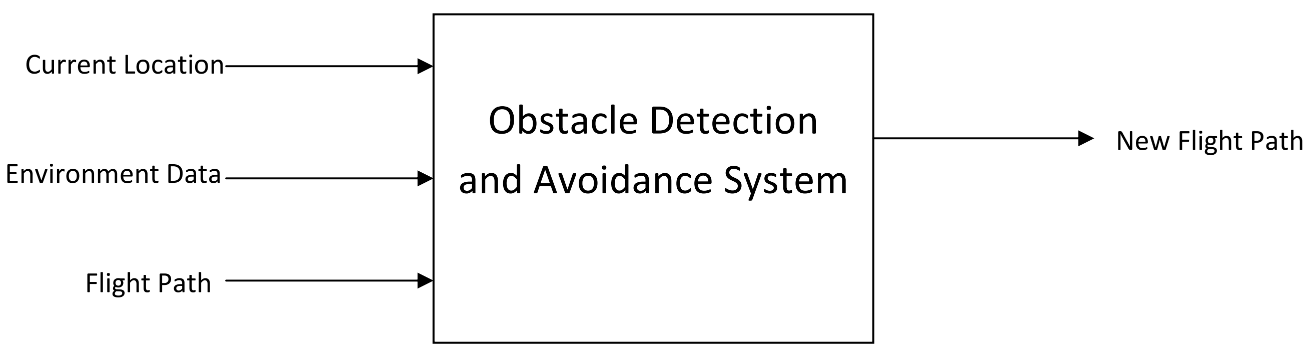

Figure 2: Level Zero Block Diagram

Table 5

Obstacle Detection and Avoidance Block Diagram Table

	Name	Description
Inputs	Current Location	The location of the UAV should both be known at all times while in flight without the use of GPS
	Environment Data	As the UAVs fly around they should gather data of the surrounding area and gather data on where objects are
	Flight Path	The UAVs will be able to operate on auto pilot mode, so when an obstacle is detected it has to have knowledge of what its original flight path is and how to change accordingly
Output	New Flight Path	The flight path is now offset and must be adjusted accordingly after avoiding an obstacle

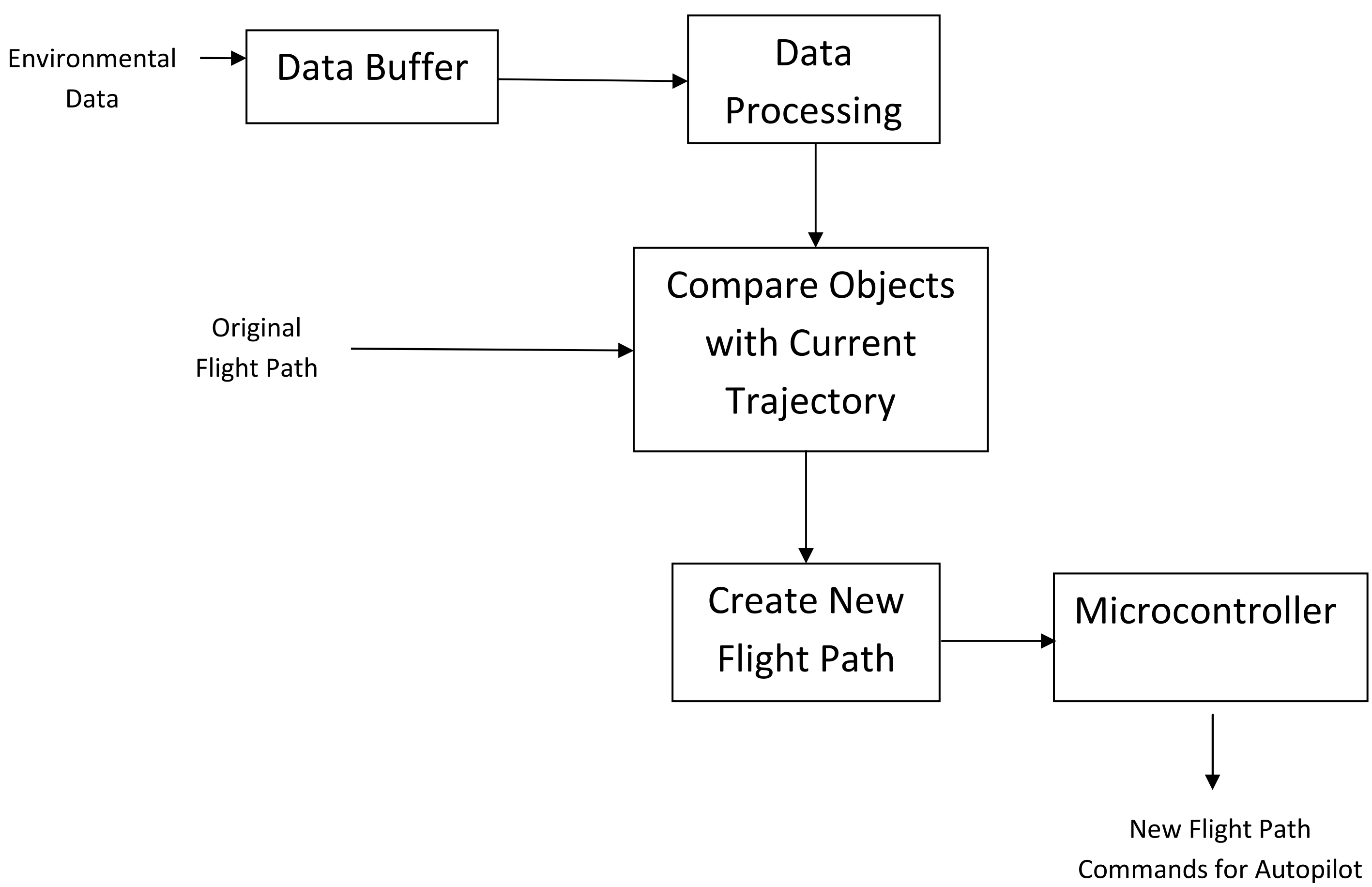

Figure 3: Level 1 Block Diagram of Obstacle Detect and Avoid System

Figure 3 shows the level 1 block diagram for the obstacle detect and avoid system. There are many components necessary in this project but for simplicity purposes this is the only block diagram included as it is the main portion of the project. Various outputs and inputs are included in the diagram and are described in Table 3 below.

Table 6
Object Detect and Avoid Level One Block Diagram Table

	Name	**Description**
Components	Data Buffer	The memory storing device that keeps track of recent locations and objects detected by the UAV
	Data Processing	Takes the detected data and does the necessary calculations to determine where the objects are as the UAV travels
	Compare Objects with Current Trajectory	This is a software portion that, after detecting an obstacle, compares where the objects are with where the UAV was originally going to travel
	Create New Flight Path	If it is determined that an object is approaching, a new flight path must be programmed to the UAV as to avoid the obstacle
	Microcontroller	This is the hardware that is coded to create new flight path which can output its data to rotate and turn the UAV.

Testing and Verification Plan:

Table 7
Testing and Verification Plan

Engineering Requirement/Specification	Plan of Verification
Fast Data Rate	Using a test code created by the Computer Engineers, data will be sent at a given rate from the transmitter to receiver to see the maximum data rate the devices can handle, various modulation techniques will be used to improve bandwidth
Functional communication at maximum distance of 1 mile	A test will be done in an open field where the transmitter and receiver will be operating at a certain data rate, the devices will be pulled away from each other to test what distances the devices can handle
No signal interference	Two sets of receivers and transmitters will be set near each other as they send data to one another, the received signal will be analyzed to see how much interference or bit errors occur

Preliminary Design

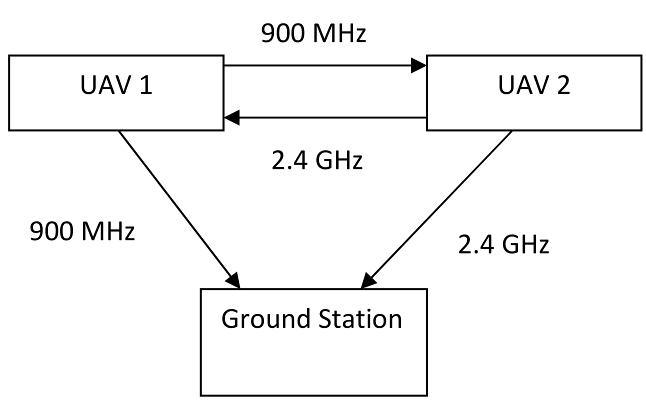

Figure 4: Zero Level Block Diagram of EE portion of project

Figure 4 shows a simple version of how the UAV's will be communicating with each other as well as the ground station. Unlike last year there will be two transceivers on the UAV's as well as two receivers at the ground station so the vehicles can communicate simultaneously. The frequencies were chosen because the antennas would not need to be too long while also maintaining a frequency that many devices that can be found online can operate at.

Table 8
Design Parameters of Communication Link

Design Parameter	Engineering Justification
Use QPSK digital modulation technique	Of all the digital modulations schemes, QPSK has the second lowest bit error rate for a given signal to noise ratio
Omni directional dipole antenna.	The location of the UAV's will not be known due to randomness of autopilot and therefore the transmitters must be able to send in all directions
Antenna with gain of 2.5dB	The gain of the signal is necessary to increase the signal to noise ratio of the system and therefore lower the bit error rate
Two Transceivers, one operating at 900MHz and the other at 2.4GHz	Two different frequencies are needed so both UAV's can transmit their own information both to the ground station simultaneously
FHSS (Frequency hopping spread spectrum)	Incorporate a modulation scheme that hops between various frequencies as to avoid any deliberate interference for security purposes.

Antenna Design

The design used for this years' demo will be to incorporate two perpendicular antennas on each UAV as transmitters using the power splitter shown below in figure 5. One UAV will have one 900MHz Xbee for transmitting, and one 2.4GHz Xbee for receiving. The receiving Xbees will only have one antenna connected. All the antennas used will be omni-directional dipole antennas. The 900MHz antennas will have a gain of 2.2dBi and the 2.4GHz antennas will have a gain of 6dBi. This is because according to the Friis transmission equation, higher frequency signals lose power quicker than lower frequency signals. The purpose of having the transmitting antennas orientated

perpendicular to each other is to achieve 360 degrees of polarization. If one transmitting antenna were to be used, then the receiver may not get enough power when the antennas are not parallel (i.e. the planes turn opposite directions or fly over the ground station).

Figure 5: RF Power Splitter

Results

Power Splitter

The first test done was using a vector network analyzer to characterize the power splitter. The vector network analyzer was configured for two port networks. One end of the power splitter was connected to a matched load so no internal reflections would occur during testing. Port 1 was connected the input of the power splitter while port 2 was connected to one output. The S parameters were observed and the results are shown below in table 9.

Table 9: S Parameters of Power Splitter

Parameter	Expected	Experimental
S11 (magnitude)	$-\infty$	-23dB
S11 (Phase)	Linear	Linear
S21 (Magnitude)	-3dB	-3.1dB
S21 (Phase)	Linear	Linear

The results in the table reveal that the power splitter achieved very close to what was expected. It is important to notice that S11 magnitude parameter would technically expect to have a value of negative infinity, but this is only in theory. Experimentally the reflection value of -23dB is still very small (only .5% power reflected, therefore negligible). When observing the phase difference it was not important to observe the actually values or slopes. It was simply necessary that the result be straight line with constant slope over all frequencies tested (850MHz

to 2.5GHz). This would mean that the two transmitting antennas will always be in phase. If at certain frequencies a linear result was not observed, then the receiver might receive the data packets at slightly different times which could cause errors.

Antennas

After observing that the power splitter achieved the expected requirements, the antennas were tested using a high frequency spectrum analyzer. The first set up was to have one transmitting antenna at 900MHz connected to a function generator and one receiving antenna connected to the spectrum analyzer. This would give results that will be compared to this year's design. The power at the receiver was observed when the antennas were parallel. The orientation of the receiving antenna was then slowly changed until the two antennas were perpendicular to each other. This would then simulate the worst case scenario that could happen during transmission in flight.

This year's design was then tested to compare to the original design. It was expected that the power at the receiver would always be higher than the original design, even in the worst case scenario. The power splitter was then connected to the function generator while the receiver stayed the same. All powers were observed and the results are listed below in table 10. In this year's design there was one transmitting antenna oriented at 0 degrees and one at 90 degrees from the horizontal. In last year's design one transmitting antenna was oriented at 90 degrees from the horizontal. The transmitter stayed at a constant power output of 17dBm (same as Xbee transmit power).

Table 10: Receiver Antenna Power

Antenna Angle from Horizontal (degrees)	Original (Last Year's) Design Power	This Year's Design Power
90	-38dBm	-40dBm
0	-48dBm - -50dBm	-40dBm
45	-45dBm	-42dBm

The results in the table show that this year's design yielded much greater power during transmission when antennas are perpendicular. Although the original design had a slightly higher power when the antennas were orientated parallel to each other, in the event of perpendicular orientation there was no power loss in this year's design, while last year's design lost nearly 10dBm (96% power).

Plans for Next Year

Anechoic Chamber Test

While the design for this year seemed to work well and better than last year's there are still other designs and testing that could be explored. This year an anechoic chamber test was expected to be done by putting the antennas in their design orientation on the UAVs and test radiation patterns. When the antennas are transmitting on the UAV, there will be some blockage by the UAV itself. The amount of power that would be blocked could not be calculated and therefore an anechoic chamber test could reveal the best places on the UAV to place to antennas for maximum power transfer.

Range Testing

This year the team was told that there could be no flying within the Cal Poly area due to the CSU rules. Therefore it wasn't possible to test the transmit and receive system while the UAVs were in the air. The tests done with the antennas were only done in the microwave lab at a short distance of just two meters. Although these results could be translated proportionally to further distances, it would be useful to see how the power changes as the distance gets closer to a mile. Additionally since antennas don't radiate upwards, it would be helpful to see how powerful the received signal is when the UAV flies close to the ground station.

References

1. Keller, John, *Air Force seeks to use existing on-board sensors to enable UAVs to sense and avoid other aircraft,* Military&Aerospace, Oct 2014

Reason for choosing source: This source explains how current technologies are being used to implement sense and avoid systems on UAVs. This source gave good insight on ideas that can help with our current project and how we can improve on current designs.

2. Guilmartin, John, *Unmanned Aerial Vehicle (UAV)*, Encylopedia Britannica, May 2014

Reason for choosing source: This source explains the general concept of UAV technology and how they are being used. It explains how they are remotely controlled and the military applications being used worldwide.

3. *Northrop Grumman Corporation,* The New York Times, Oct 2014

Reason for choosing source: This source offers a very broad background of the Northrop Grumman Corporation. It gave numbers involving how much funding Northrop Grumman has and who their key markets are.

4. Lee, Eloise, *The 25 Biggest Defense Companies in America,* Business Insider, Mar 2012

Reason for choosing source: This source gives a list and description of all the top defense contractors for the United States. This explains in broad detail what other competition there is in the defense market as well as companies that Northrop Grumman works with.

5. Chantrill, Christopher, *US Defense Budget,* US Government Spending, Oct 2014.

Reason for choosing source: This source explains in detail how the United States defense budget is divided. It shows how much money the defense market receives and how that budget has been changing in the past years.

6. Mead, Derek, *The Military's Budget for New Drones Is Bigger in 2015,* Motherboard, Mar 2014

Reason for choosing source: This source explains how the budget specifically for UAV technology is going to change in the upcoming years. It shows how much money went into specific UAVs and how increases are going to be made in the next year for certain drone technologies.

7. Epatko, Larisa, *How Are Drones Used in the U.S.?,* PBS, Apr 2013

Reason for choosing source: This source outlines the ways in which the United States is using drone technology. Drones can be used for various reasons whether it be for surveillance or missile tactics. The project we are working on focuses on providing coverage of an area for a given amount of time but for market research it is

necessary to know how the defense budget is being used in regards to all drone technology.

8. Govers, Francis, *General Atomics tests UAV that can “sense and avoid” other aircraft,* Gizmag, Dec 2013

Reason for choosing source: This source additionally outlines how other companies other than Northrop Grumman are trying to implement sense and avoid technology. This directly relates to our project and we must design a project that is not already in the making. However, it does explain overall the kind of technology that the company is implementing on their drones.

9. Berger, Ivan, *Drone Control,* The Institute, Oct 2014

Reason for choosing source: This source explains how drone technology is starting to incorporate, not just defense, but commercial uses. Companies such as Google and Amazon are trying to use drone technology as a delivery system through the use of advanced electronics and accurate communication systems. While this does not relate to our specific project it does still include the UAV market and how different companies are trying to use UAV technology in various ways.

10. Board of Directors. *Department of Defense Science and Technology,* IEEE, Nov 2013

Reason for choosing source: This source outlines the goals and importance of the Department of Defense. This is relevant for market analysis purposes in explaining what the overall tasks the large defense companies are trying to accomplish. It gives examples of the budget that the department is dealing with and what has been provided by the government over past years.

Senior Project Analysis

1. **Summary of Functional Requirements**

   The UAVs will utilize a sense and avoid system onboard the aircraft that can detect when there are nearby objects and change their autopilot course accordingly. It must operate without the use of GPS while still being able to keep track of its coordinates during a given flight. A ground station will be set up that

communicates with the two UAVs over a frequency within the legal band over a range of one.

2. Primary Constraints

The primary constraint within this project is the budget that we have to work with. Since this is a sponsored project Northrop Grumman is funding the project with 10 thousand dollars which the group must not exceed. The project is also working with very low level programming, specifically C, which makes the flexibility of the system a little lower. A constraint given to us that will lead to some issues is operating without the use of GPS. GPS was used in this project in past years but this new challenge is being implemented for the next demonstration at the end of the year. A system must be incorporated into the aircrafts that can still keep track of where in space both aircrafts are through a form of wireless communication.

3. Economic

This project requires hours of work from various engineers all concentrating in a range of specialties to create a fully functioning design. Profit could arise from this product being developed in that companies could utilize multiple UAVs without the use of human control. In order to implement this kind of design on a full scale UAV to be used for military purposes would also take some time. During that time materials would have to be bought and the company would not make the money until the product was complete. Also the company is funding this project which will set them back that much money for cost of materials and supplying the aircrafts. During this project's lifestyle costs mostly come from the communication devices and the UAVs themselves. This project consists of a lot of software coding that do not require purchasing. The project is fully funded by Northrop Grumman so long as the team stays within the cost requirement. The initial estimated costs and actual final costs are listed below in tables 1 and 2 respectively. Products are supposed emerge during the demo near the end of May, when everything is finalized.

Table 11
Beginning Estimated Costs (Wireless Comms)

Item	Number	Cost
Xbees	4	$200
Antennas	6	$75
Power Splitter	2	$10
Total		$285

Table 12
UAV Sense and Avoid System Final Costs (Wireless Comms)

Name	Quantity	Price
HUACAM 2.4GHz 6dBi Indoor Omni-directional Antenna	4	$22.20
Xbee Pro 63mW RPSMA	3	$134.85
Super Power Supply, SMA Male to 2 SMA Female T RF Adapter	2	$2.18
AIR802 2.5dBi Dipole Antenna with RP-SMA Connector	4	$35.8
Total		$195.03

4. If Manufactured on a Commercial Basis

In the defense industry about $2.9 billion goes into drone research every year. The pentagon itself has an estimated 7000 drones in effect right now. These drones each cost about $3000 per hour of flight. The yearly costs vary depending on how much the UAV's are used. The project at hand using the UAV's funded by Northrop Grumman will cost as much as buying new batteries when needed and charging the ones that are currently being implemented. The profit for the projects varies depending on how much the government spends on funding these projects. It is estimated that the net revenue of three companies, General Atomics, Northrop Grumman, and Textron is about $3 billion.

5. Environmental

The main environmental issue that comes with this project is the manufacturing of all the chips that will go on board the aircraft. Making silicon chips involves using various chemical processes that can be harmful to the environment. Additionally the UAVs used in industry run off of fuel for power which can cause an increase in air pollution. Since this is an aircraft vehicle it is difficult to incorporate electric power onto the system so fuel is the main source of power for flight. Overall the system itself does not cause too much environmental harm once manufactured.

6. Manufacturability

This is a large scale project and therefore is required to be funded by a defense company for manufacturing purposes. Our group has been given the aircraft vehicles which we will incorporate the sense and avoid system onto.

However, the UAVs the company uses for actual defense purposes require much more manufacturing too large for a small group. At this point drone technology has become very cheap and therefore it does not take too much to put into manufacturing. The issue would be incorporating a whole new system onto an already existing UAV because then the weight must be taken into account as well as all the communication systems existing on the aircraft.

7. Sustainability

There are many challenges that come along with sustaining this project once implemented. Once completed the aircraft system must be able to operate for an hour while maintaining all necessary coordinates and maintaining its autopilot path. The batteries on board the system must be able to supply the correct amount of power for the desired amount of time which will be calculated by the datasheet we find. Certain batteries will not be able to sustain power for long enough so we must do research on what will work best. Additionally the aircraft must be able to withstand any wear and tear that occurs especially during landing when it goes through the most impact. Lastly the sense and avoid system must be able to operate 100 percent of the time because in the event that the system fails then the aircrafts will sustain damage that would most likely make them unusable. Therefore the system we implement (hardware and software) must be able to work as efficiently as possible. To ensure the hardware does not fail we will have to carefully observe the datasheet and specs for each component to make sure none are drawing too much power at any time.

8. Ethical

The ethical implications that come with this project are the use of the system for surveillance reasons. Since Northrop Grumman works for as a security company for the United States, their innovations are to be used for anything can provide a safe environment for the country. Some of the uses of these technologies may not be seen as ethical in that it can disturb the privacy of others.

9. Health and Safety

This project doesn't offer much health or safety issues during manufacturing. However, the finished product must operate with perfect efficiency in that it must be able to perfectly avoid objects as necessary. Since these aircrafts will be flying around and high speeds they can cause damage to each other or surrounding obstacles during flight. Additionally if the aircrafts lose power during flight they will coast to the ground but there will be no control of where they land

which can be dangerous to the anything in the area they are flying over.

10. Social and Political

This project is directly used for defense purposes that are decided by the United States government. Social and political issues that could arise depend on how the government decides to use the technology. The government has used drones for aerial strikes which has caused dispute among Americans over whether it is a moral thing to do. While these UAVs are not weapon related they are made to provide long surveillance or given areas which could cause issues of whether it is moral to take surveillance of certain places. There would not be a real social issue with the creation of the project as it would not be available to the commercial market and would only be used for military purposes.

11. Development

This project taught the various ways antennas can be incorporated to communicate with moving objects. Because of the random movement of the UAVs it was necessary to look into omni-directional antenna configurations instead of directional ones. This also enhanced knowledge of using the vector network analyzer by observing S parameters of a power splitter before connecting the antennas to it to ensure the signals would be in phase.

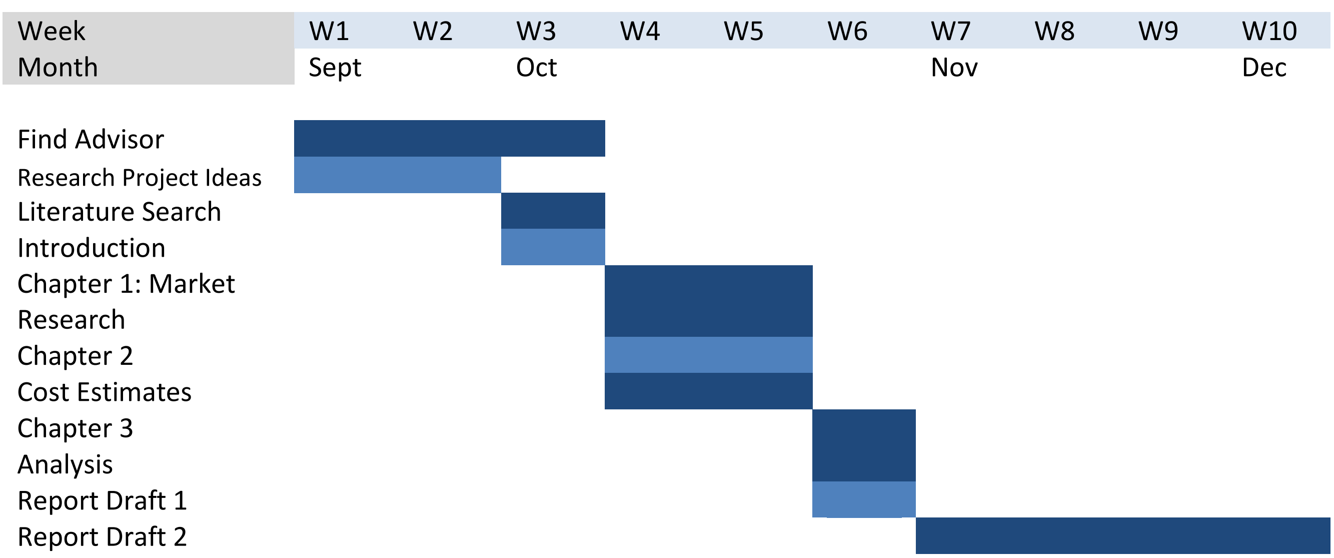

Figure 6

Gantt Chart Fall 2014

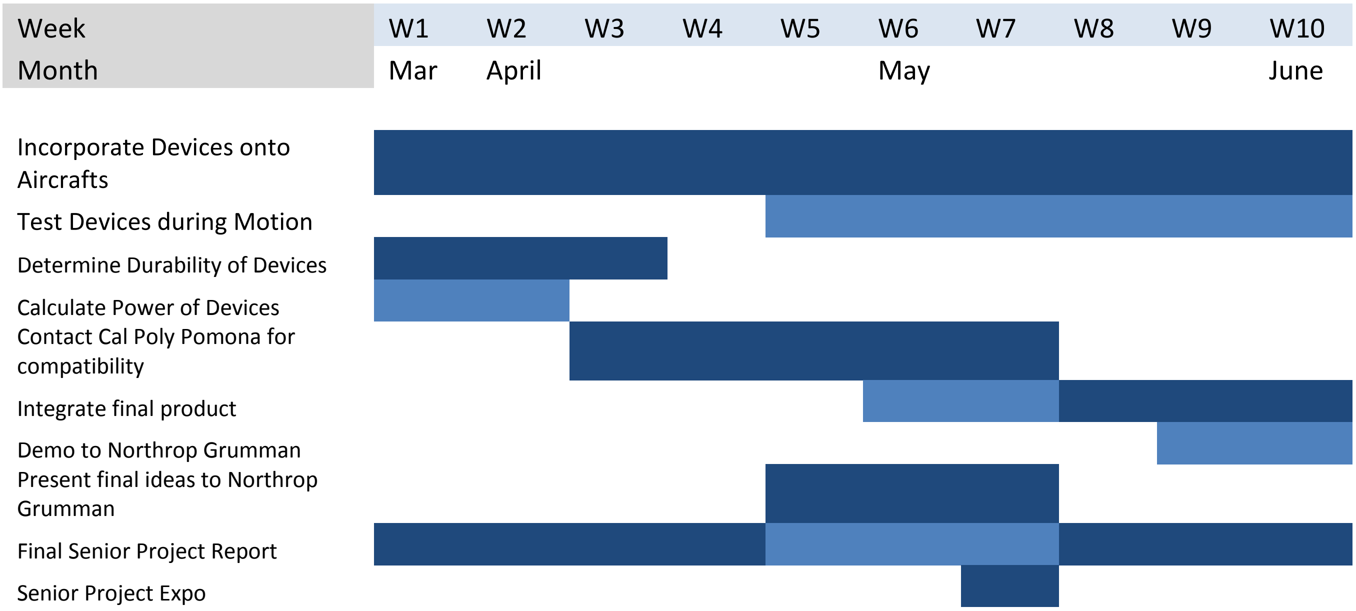

Figure 7:
Gantt Chart Winter 2015

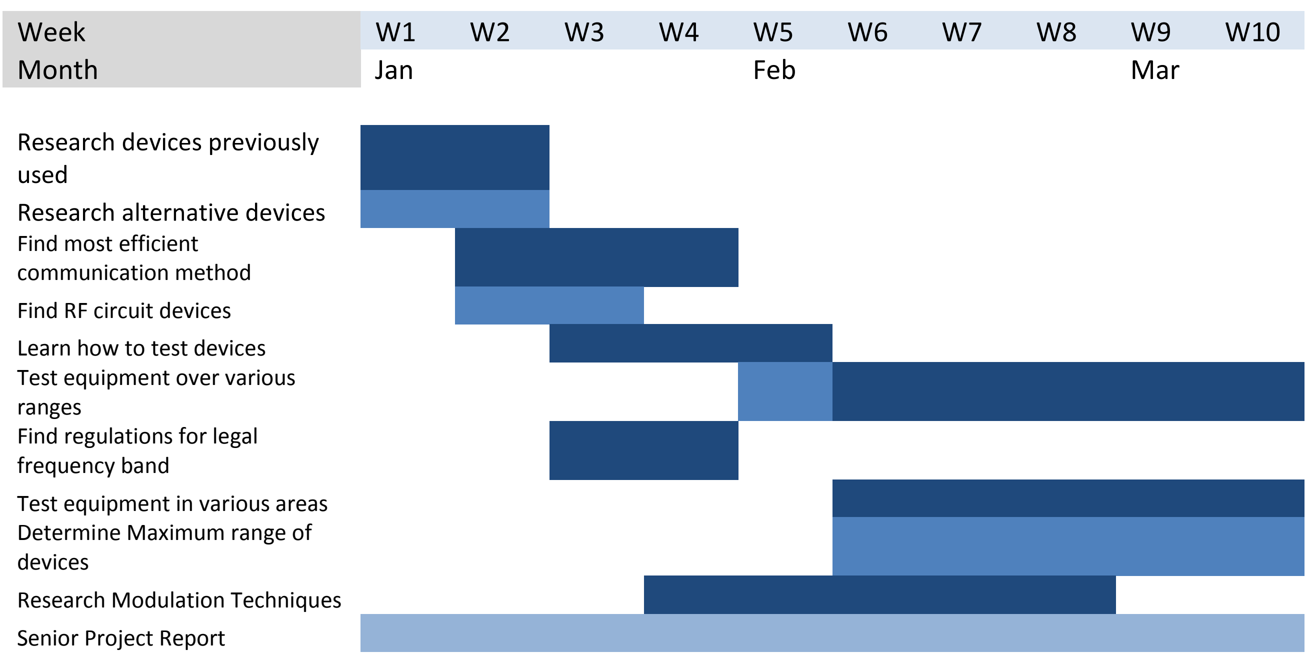

Figure 8
Gantt Chart Spring 2015

Literature Search

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5. Chantrill, Christopher, *US Defense Budget,* US Government Spending, Oct 2014.

6. Mead, Derek, *The Military's Budget for New Drones Is Bigger in 2015,* Motherboard, Mar 2014

7. Epatko, Larisa, *How Are Drones Used in the U.S.?,* PBS, Apr 2013

8. Govers, Francis, *General Atomics tests UAV that can "sense and avoid" other aircraft,* Gizmag, Dec 2013

9. Berger, Ivan, *Drone Control,* The Institute, Oct 2014

10. *Department of Defense Science and Technology,* IEEE, Nov 2013

Parts List

Name	Quantity	Price
HUACAM 2.4GHz 6dBi Indoor Omni-directional Antenna	4	$22.20
Xbee Pro 63mW RPSMA	3	$134.85
Super Power Supply, SMA Male to 2 SMA Female T RF Adapter	2	$2.18
AIR802 2.5dBi Dipole Antenna with RP-SMA Connector	4	$35.8