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UNMANNED AERIAL VEHICLE
25% of Final Report

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Luis Ramos, Daniel Reyes, and Alejandro Diaz and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, and design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Abstract

The focal object of the competition is to create and operate an unmanned aerial vehicle that is capable of autonomous target reconnaissance, navigation, takeoff and landing operations. The judges will score the participants based on their system's performance composed of three sections: a final journal paper, oral presentation, and a flight demonstration. It is a performance-based competition where multiple government agencies and corporate partners will be in attendance. As part of the senior design project, we will be designing the platform, assembling the components and programming the navigation, flight control and image recognition algorithms needed to identify the targets and complete the proposed mission objectives.

Problem Statement

Design an autonomous and unmanned aerial platform capable of control and target acquisition. The designed aerial platform should be capable of achieving these objectives at a standard high enough to compete in the UAS AUVSI Seafarer competition.

Motivation

The inspiration for the proposed project arose from a variety of reasons. The first major reason for choosing such a project is the ability the project has to involve each team member. It is believed that designing the platform and target recognition program will adequately fulfill the requirement. The most important aspect is to make sure all three team members utilize the four years of undergraduate studies in mechanical engineering.

Florida International University is an up and coming University. Over the years, it has become well known over the community as well as the country. The University is seeing improvements each day and is expanding at a rapid pace. Entering the AUVSI Seafarer competition allows for the opportunity to showcase the Mechanical Engineering Department at

Florida International University. During this competition, many companies will be in attendance and the most motivating aspect of this project is the chance to win and promote the University.

Literature Survey

The project literature survey began by looking at previous teams who had competed in the competition in earlier years. Speaking with the ex-competitors and faculty familiar with the matter presented a broad overview of what the competition involves. A brief survey of teams from other universities, which are available upon request from the AUVSI representatives, also provided insight on the overall scope of the competition and the aspects contained.

Further investigation encompassed reading material, which was closely related with the subject of unmanned platform operations. According to Valavanis autonomy is single most difficult mechanism to incorporate into any system. [1] In this text, the complex art of autonomous flight techniques are discussed and depicted in diverse forms to offer intuitive methods for programing and incorporating these techniques to aerial platforms.

Figure 1: Previous AUVSI Seafarer Competitor equipped with autonomous systems [4]

Additional review consisted of mostly physical and mechanical properties associated with flight. After considering all the possible conceptual design ideas and history of success in the competition, an overwhelming appeal towards helicopters formed. Studying texts such as *Bamwel's Helicopter Dynamics,* an insightful literature on flight mechanics of vertical lift platforms provided an insightful view of the subject. A brief section of the text discussed the integration of computer chips to achieve autonomous flight and the differences between each of the mechanics. This offered an immense benefit for our project as it described detailed information on how to convert the mind behind the pilot of the platform to a computer chip, which uses algorithms to replicate the complex process of flying a helicopter.

Project Objectives

The primary objective of this project is to investigate and construct a system for aerial vehicles that will allow for autonomous operation and target recognition. Case study and mentor guided research into existing methods will be examined and improved upon to conform to realistic objective, platform, and budget constraints. Implementation of those methods will be done upon optimizing computer and programming language combinations in order to improve system efficiency. The system will then be outfitted with cameras and sensors in order to identify and track objects of interest using GPS technology.

Conceptual Designs

Every team entering the competition is free to choose an aerial platform that will perform the specified tasks. The team went through careful research and investigation of three main platforms; helicopter, fixed wing airplane, and multi-rotor copter. Among these three platforms are considerable advantages and disadvantages that must be taken into account before choosing the optimal platform. Helicopters and multi rotor copters have similar advantages as they are allowed to take off and land virtually anywhere. Both platforms can hover in one place and can move in any axis from a point with great maneuverability. Each style can carry a small payload if necessary but travel slowly, with the multi rotor travelling a bit faster. Planes on the other hand can travel large distances at a faster rate. Planes have the ability to be designed simpler and repair costs are considerably less than multi rotor platforms.

Figure 2: Conceptual Design – Plane [2]

While all three platforms show tremendous upside, each has its own fair share of disadvantages. Multi rotor platforms require rigorous programming along with tedious calibration of the motors. The weight of a multi rotor platform must be distributed evenly as to avoid over compensating a motor. A major setback for multi rotor platform is in flight issues, if a motor decides to give out, the aerial vehicle will shortly come to a fall. Planes alike the multi rotor platforms must have the weight distributed evenly. They also have the disadvantage at take-off and landing as they require plenty of space to perform both tasks. Overall, the plane requires a great deal of space to fly in to avoid any crashes. Lastly, the helicopter has the most complex design among the three platforms. This complexity is usually prone to failure if not properly designed. A helicopter requires more maintenance then the other two platforms.

Figure 3: Conceptual Design – Multi Rotor [2]

Proposed Design

Carefully considering all advantages and disadvantages of all three platforms, the team is deciding on carrying out the project with the design of a helicopter. For the task at hand, the helicopter offers the best possible results. Take-off and landing are important factors in the competition due to the time constraints placed. The team believes using a helicopter will avoid take-off issues and save much needed time. While planes do cover ground better than helicopters, the helicopter has the ability to fly slow and also hover in one location. This alone makes the helicopter the most intriguing as the design must perform target recognition. The ability to hover and simultaneously scan the area for targets is a great advantage. The last factor in terms of capability is the maneuverability in any axis. The ability to change direction quickly and decisively will prove a strong point in the design. The multi rotor platform was an intriguing option as it provides similar benefits as the helicopter. The main issue is the simplicity in the design. The helicopter not only provides a platform to compete but also challenges the team in making a complex design.

Figure 4: Proposed Design – Helicopter [3]

Timeline

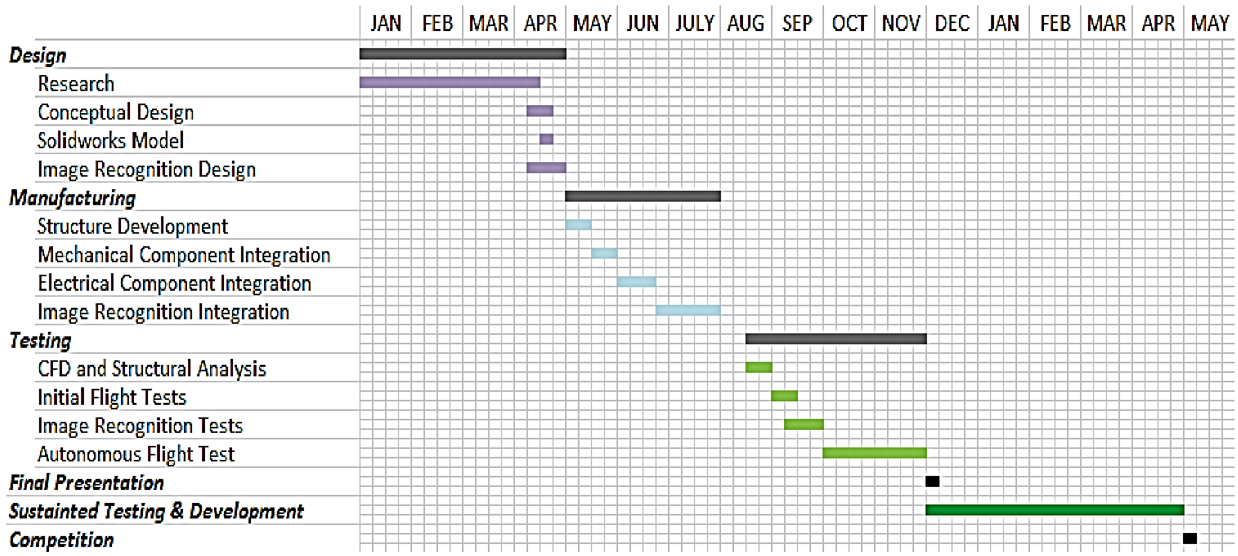

Figure 5: Overview of Project Timeline

The projected timeline illustrated in Figure 5 shows an overview of key tasks needed for a successful completion of the project before final senior design presentation and competition due dates. For this proposed timeline, the total number of man-hours needed from our group is an approximate 10 hours a week. Taking into consideration other responsibilities from each of the team members will account for approximately 350 total hours before senior design presentation and 400 hours before competition day.

Additionally, a breakdown of responsibilities among team members includes 3 main components. Alejandro Diaz will be mainly responsible for the development of the Image recognition software and electrical components associated with it. Luis Ramos will be in charge of flight mechanics and controls of the platform including the autopilot for autonomous use. Lastly Daniel Reyes will be responsible for the design and construction of the structure to house all the components. As a team project, all team members will assist in respective ways according to each member's specific expertise.

Major Components

Major components for this project include mostly the hardware required for the construction of the UAV platform. Basic material and flight components include the frame structure, engine, rotor mechanics, etc. Additionally key electrical components along with image recognition devices must also be integrated to this list. A clearer more concise representation of the major components required for this project can be seen in Table 1.

Table 1: Major Components List

- Zenoah G231 23cc Gasoline Engine
- 600/700 Size Main & Tail Rotor Head Mechanics
- Rotor Tech 700 Carbon Fiber Main Blade
- Rotor Tech 105 Tail Blade
- Beagle Bone Processor
- Ultrasonic Range Finder
- Autonomous Gear
- Accelerometer
- Gyro Sensors
- Miscellaneous Gear

Structural Design

A main aspect of the project is structural design. A helicopter has many components which can be designed for maximum efficiency of a particular task. One of the main features surveyed was the rotor mechanics design. A helicopter's main rotor or rotor system is the combination of a rotary wing and a control system that generates the aerodynamic lift force that supports the weight of the helicopter, and the thrust that counteracts aerodynamic drag in forward flight. The helicopter rotor is powered by the engine, through the transmission, to the rotating mast. The mast is a cylindrical metal shaft that extends upward from—and is driven by—the transmission. At the top of the mast is the attachment point for the rotor blades called the hub. The rotor blades are then attached to the hub. Main rotor systems are classified according to how the main rotor blades are attached and move relative to the main rotor hub.

There are three basic classifications: rigid, semi rigid, or fully articulated, although some modern rotor systems use an engineered combination of these classifications, while usually designed to operate in a narrow range of rpm.

One of the designs considered is the rigid rotor. The term "rigid rotor" usually refers to a hinge less rotor system with blades flexibly attached to the hub. Irven Culver of Lockheed developed one of the first rigid rotors, which was tested and developed on a series of helicopters in the 1960s and 1970s. In a rigid rotor system, each blade flaps and drags about flexible sections of the root. A rigid rotor system is mechanically simpler than a fully articulated rotor system. Loads from flapping and lead/lag forces are accommodated through rotor blades flexing, rather than through hinges. By flexing, the blades themselves compensate for the forces that previously required rugged hinges. The result is a rotor system that has less lag in control response, because the rotor has much less oscillation. The rigid rotor system also negates the danger of mast bumping inherent in teetering rotors

Figure 6: A MBB Bo 105 – an example of a rigid rotor helicopter [5]

The semi-rigid rotor can also be referred to as a teetering or seesaw rotor. This system is normally composed of two blades that meet just under a common flapping, or teetering hinge at the rotor shaft. This allows the blades to flap together in opposite motions like a seesaw. This under slinging of the blades below the teetering hinge, combined with an adequate dihedral or coning angle on the blades, minimizes variations in the radius of each blade's center of mass from the axis of rotation as the rotor turns, which in turn reduces the stress on the blades from lead and lag forces caused by coriolis effect. Secondary flapping hinges may also be provided to provide sufficient flexibility to minimize bouncing. Feathering is accomplished by the feathering hinge at the blade root, which allows changes to the pitch angle of the blade.

Figure 7: An example of a Semi-Rigid Rotor [5]

The last commonly used configuration is known as the fly bar or stabilizer bar design. A number of engineers, among them Arthur M. Young in the U.S., and Dieter Schlüter in Germany, found that flight stability for helicopters could be achieved with a stabilizer bar or flybar. The flybar has a weight or paddle (or both for added stability on smaller helicopters) at either end. These keep the bar relatively stable in the plane of rotation, and reduce crosswind thrust on rotors. Through mechanical linkages, the stable rotation of the bar mixes with the swashplate movement to damp internal (steering) as well as external (wind) forces on the rotor. This makes it easier for the pilot to maintain control of the aircraft. Stanley Hiller arrived at a similar method to improve stability by adding short stubby airfoils, or paddles, at each end; However, Hiller's "Rotormatic" system also delivered cyclic control inputs to the main rotor as a sort of control rotor, the paddles provided the added stability by dampening the effects of external forces on the rotor. The Lockheed rotor system used a control gyro, similar in principle to that of the Bell stabilizer bar, but designed for both hands-off stability and rapid control response of the hinge less rotor system. In fly-by-wire helicopters or RC models, a microcontroller with gyroscope sensors and a venturi sensor can replace the stabilizer. This flybar-less design has the advantage of easy reconfiguration and fewer mechanical parts.

Modern rotor systems may use the combined principles of the rotor systems mentioned above. Some rotor hubs incorporate a flexible hub, which allows for blade bending (flexing) without the need for bearings or hinges. These systems, called "flextures" are usually constructed from composite material. Elastomeric bearings may also be used in place of conventional roller bearings. Elastomeric bearings are bearings constructed from a rubber type material, and provide limited movement that is perfectly suited for helicopter applications. Flextures and elastomeric bearings require no lubrication and, therefore, require less maintenance. They also absorb vibration, which means less fatigue and longer service life for the helicopter components. For the purpose of this project, the most effective and efficient design would tend more towards a combination of the systems described.

A secondary feature that requires structural analysis when dealing with helicopters is rotor configuration which mainly concerns the anti-torque production. This is accomplished through a variable pitch, anti-torque rotor or tail rotor. This is the design that Igor Sikorsky settled on for his VS-300 helicopter and it has become the recognized convention for helicopter design, although designs do vary. When viewed from above, the main rotors of helicopter designs from Germany, United Kingdom, The United States and Canada rotate counter-clockwise, all others rotate clockwise. This can make it difficult when discussing aerodynamic effects on the main rotor between different designs, since the effects may manifest on opposite sides of each aircraft.

With a single main rotor helicopter, the creation of torque as the engine turns the rotor creates a torque effect that causes the body of the helicopter to turn in the opposite direction of the rotor. To eliminate this effect, some sort of anti-torque control must be used, with a sufficient margin of power available to allow the helicopter to maintain its heading and provide yaw control. The three most common controls used today are the traditional tail rotor, Euro-copter’s Fenestron (also called a fantail), and MD Helicopters' NOTAR

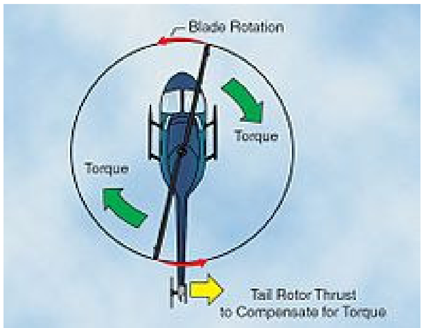

Figure 8: Free Body Diagram of Torque on a helicopter [5]

The two main designs considered were, coaxial or counter rotating rotors or the more common tail rotor. The tail rotor is a smaller rotor mounted so that it rotates vertically or near-vertically at the end of the tail of a traditional single-rotor helicopter. The tail rotor's position and distance from the center of gravity allow it to develop thrust in a direction opposite of the main rotor's rotation, to counter the torque effect created by the main rotor. Tail rotors are simpler than main rotors since they require only collective changes in pitch to vary thrust. The pitch of the tail rotor blades is adjustable by the pilot via the anti-torque pedals, which also provide directional control by allowing the pilot to rotate the helicopter around its vertical axis (thereby changing the direction the craft is pointed). Coaxial rotors are a pair of rotors mounted one above the other on the same shaft and turning in opposite directions. The advantage of the coaxial rotor is that, in forward flight, the lift provided by the advancing halves of each rotor compensates for the retreating half of the other, eliminating one of the key effects of dissymmetry of lift: retreating blade stall. However, other design considerations plague coaxial rotors. There is an increased mechanical complexity of the rotor system because it requires linkages and swashplates for two rotor systems. Also, because the rotors must rotate in opposite directions, the mast is more complex and control linkages for pitch changes to the upper rotor system must pass through the lower rotor system

Cost Analysis

A project of this magnitude requires a considerable budget to fulfill all of the objectives set forth. A cost analysis would include cost for material parts including engine, blades, rotors servos as well as electronic components necessary for autonomous flight and image recognition devices. A rough estimate of the initial components necessary to begin working and designing a working model can be seen illustrated in Table 1.

Table 2: Major Component Budget Estimate

Major Component Budget	
	Price Estimate
Zenoah G231 23cc Gasoline Engine	$339.99
600/700 Size Main & Tail Rotor Head Mechanics	$229.00
Rotor Tech 700 Carbon Fiber Main Blade	$99.00
Rotor Tech 105 Tail Blade	$24.95
Beagle Bone Processor	$89.00
Ultrasonic Range Finder	$29.95
Autonomous Gear	$500.00
Accelerometer	$29.95
Gyro Sensor	$49.95
Miscellaneous Gear	$300.00
Total	**$1,691.79**

As illustrated in Table 2, a considerable amount is needed in order to even start the project and be able to design and construct a platform capable of achieving the goals projected. After the project is completed there will be extensive testing from the time of presentation to the competition due date. This will require additional budget for test flights that require fuel, battery power, extra components which may fail or need regular maintenance.

Table 3: Testing Budget Estimate

Sustained Testing & Replacement Budget	
	Price Estimate
Fuel Cost	$200
Battery Cost	$40
Replacement of Mechanical Parts	$200
Replacement of Electrical Parts	$50
Replacement of Flight Parts	$89
Miscellaneous Part and Fuel Replacement	$150
Total	**$729.00**

Additionally, entering and competing in the competition also requires quite a considerable sum of the budget. The competition will span over a weekend were all team members must provide individual transportation, lodging and any competition costs. Budget requirement for the competition itself including an aggregate budget analysis for the overall project is illustrated in Table 4.

Table 4: Competition Budget Estimate

Competition Costs	
	Price Estimate
Entrance Fee	$599
Lodging (All members)	$300
Travel (All members)	$200
Other Expenses	$100
Total	**$1,199.00**
Aggregate Total	**$3619.00**

Prototype System Description

A prototype of the proposed system is being designed in SolidWorks. Component selection is contingent on the project's budget, funding, and technical requirements of which currently is not been established. However a basic plan of the system has been started in order to give an overall sense of the scope and technical requirements of the project and what is needed to accomplish the competition objectives.

Specifications

Mechanical

Main Blade Length – 700 millimeter

Tail Blade Length – 105 millimeters

Overall length – 1.7 meters

Overall Weight – 9 pounds (estimate)

Engine – 2.2 HP Zenoah G231 23cc Gasoline Engine

Fuel Capacity – 700 cc

Carbon Fiber and Aluminum frame construction

Selection for the mechanical components was chosen to satisfy the requirements imposed by the nature of the helicopter design. The helicopter must be able to operate and maneuver quickly while still able to carry the load of the extra electronic equipment. The engine and blade selections were chosen as such that limitations on the performance of the helicopter will not be encountered by over designing.

Electrical

Accelerometer – 9 axis

Ultrasonic range finder – 5 meter range

Miscellaneous servo motors for movement control

Gyroscope sensor for stability control

Autopilot module for autonomous GPS course mapping and navigation

Computer

Beaglebone – 700 MHz 512 MB RAM ARM Cortex open source development board

Operating System – Embedded Angstrom Linux distribution

Power consumption – 5 volts at 500 milliamps

Camera – Logitech c260 HD USB camera

The Beaglebone will be computer that will be in charge of image recognition and target acquisition. It is an open source development board similar to an Arduino microcontroller or Raspberry Pi but much more powerful. It has a 700 MHz ARM Cortex processor, 3D graphics accelerator, USB and Ethernet inputs, SD card slot and 2x46 pin headers for sensor input/output and at a footprint of 3.4 x 2.1 inches it will easily be incorporated into the helicopter's chassis. An Angstrom Linux distribution will be running the system running custom programming based on the OpenCV set of libraries. Open CV is an open source library of programming functions for image recognition.

A USB computer HD camera will be used to acquire the targets. This camera was chosen for its small form factor and quality of image in outdoor settings.

Prototype Cost Analysis

Design considerations are carried out depending on the available funding and on the technical requirements of the objectives the drone must accomplish. To this end the prototype is currently being designed with optimal, yet realistically attainable components. In the event that the funding or performance is simply not achieved, a contingency plan for alternate components has been created in order to ensure that the project is kept on schedule.

The BeagleBone open source development board is of interest for this project as it is a high performing, low power processing unit capable of running the software necessary to carry out the programming of an autonomous drone. The board retails at $89 boasting a 700 MHz processor and 512Mb of RAM capable of running Linux. If this option should not live up to expectation the next recourse will be to upgrade to the BeagleBoard development board. This board costs $150 and is featuring a 1.2 GHz dual core processor with 1 GB of ram also capable of running Linux. They share a similar architecture so in the event that an upgrade should be done the underlying programming for the platform will be compatible between the two models which will save redevelopment time.

Plan for Tests on Prototype

Plans for prototype testing include testing individual components of the drone as they are completed and then tested again once the platform has been assembled. The image recognition system is scheduled to be completed by end of June. Objectives for completion include target acquisition, color and shape identification as orientation of the target from various angles. The method of testing will be to show shapes of different colors to the system and a tabulated result will be output with the image data. A Wi-Fi transmitter will be then incorporated to transmit the signal back to a base computer. Finally the auto pilot and GPS equipment will be tested by monitoring the output for proper operation. The helicopter drone will not be operational however the system must still be tested to verify that the board is sending and receiving proper signals and that it is actuating the servos correctly.

The mechanical portion is scheduled for completion for the beginning of August. The helicopter will be tested at first with radio control to verify the mechanical components. It will be deemed successful if the helicopter is able to operate under normal conditions.

Integration of the computer and navigation equipment will follow and is scheduled to be completed by the end of August. This includes the installation of the computer, navigation and camera equipment. Image recognition and target acquisition will be initially tested by manually flying the helicopter. The helicopter will fly over targets as described in the competition rulebook. The success of the system will be achieved when it is able to correctly identify the targets while operating at competition conditions. The next step in testing will be done on how the computer and auto navigation is able to autonomously control the helicopter. Successful integration of the auto pilot will be achieved when the system is able to navigate a set of GPS waypoints and return back to base. At this time the Wi-Fi equipment will be tested by transmitting diagnostic information to the base computer in order to monitor reliability.

Once the individual systems have been successfully integrated the drone will have to perform the same exercises as described in the rule book. The testing of the drone will be a success if at a minimum the drone is able to follow a pre-determined flight course, identify the targets and return back to base autonomously.

Conclusions

Conclusions to our project so far are fairly limited to the scope and proposed design. A decision was made following the literature survey to choose a helicopter for the many reasons described to compete in the competition. Using a helicopter as a platform should provide the greatest efficiency in maneuverability and time sensitive operations during testing and for competition. The separate responsibilities have been well defined for each group member and have been taken into effect thus far.

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Appendices