UAV Concordia

Journal Paper for the AUVSI Student UAS Competition

Abstract

This document will provide to the reader a proposal in response to a bid launched by the Association for Unmanned Aerial Systems International to all international undergraduate design teams in the context of the 2017 Student Unmanned Aerial Systems (UAS), aiming to put students in a simulation. The tasks involved in this simulation require a system capable of numerous advanced features including autonomous flight, navigation and automated target detection. The UAV Concordia team offers a solution to those challenges which was elaborated by undergraduate students mostly from the faculties of software, electrical and mechanical engineering. This year's competition shall be UAV Concordia's attempt to compete on the field.

UAV CONCORDIA

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1. SYSTEMS ENGINEERING APPROACH

1.1. MISSION REQUIREMENTS ANALYSIS OF PLANNED TASKS

The development process of the UAV to be used during the competition has been carried out with special consideration to the various tasks and objectives outlined in the competition rules. In all, our platform was arranged in order to maximize flight time while ensuring a structural integrity of the frame, integrated image processing capabilities and reliable signal transmission.

- **<u>All primary objectives are expected to be achieved. Several optional objectives are also considered to be fully achievable</u>**
    - Autonomous Flight Task
    - Search Area Task
- **<u>Objectives that will be attempted:</u>**
    - Actionable Intelligence Task
    - Off-Axis Task
    - Payload Drop
    - Emergent Target Task
    - Interoperability Task
- **<u>Objectives that will not be attempted</u>**
    - Automatic Detection, Localization, and Classification (ADLC) Task
    - Simulated Remote Information Center (SRIC) Task
    - Sense, detect and avoid (SDA) Task

1.2. DESIGN RATIONALE

- **Environmental Factor - Team Qualifications**

  The UAV Concordia team comprises of students mostly from the programs of Mechanical, Electrical and Software Engineering. Team leaders for each team had been appointed based on factors of experience within the society but also for years of study completed. This way, leads in their third and fourth-year of engineering possess both the theoretical and practical knowledge to effectively coordinate teams to design systems that will meet the mission requirements for the competition. The society emphasises on design choices that will maximize the opportunities for members to learn and develop technical skills. This approach will often translate into designing our own parts instead of outsourcing because of the valuable hands-on experience it will provide a team member, even though this might be slightly more time intensive and pricier.

- **Environmental Factor - Budget**

  Each academic year, UAV Concordia applies and is assigned a yearly budget from its umbrella student association, the Engineering and Computer Science Association (ECA). This primary source of funding from the ECA is not sufficient to cover the expenses related to the design and manufacturing of the systems and the expenses incurred by attending competition. For this reason, the society also reaches out to corporate sponsors and other organizations for additional sources of financial support. On each occasion when a new part is needed for a system, a process to find equivalent components at a lower cost is engaged to optimize the use of funds.

- **Mission Requirement - Battery Configuration (Flight Time)**
  - The main criterion in selecting the most appropriate battery configuration for our drone included the following requirements;
    - The voltage output for the batteries must be in accordance with the 22.2V of voltage required for the propeller motors. As such, a 6-cell lithium-polymer battery is to be used.
    - The energy capacity of the battery should allow for flight times of up to 22 minutes. For that reason, a battery with a capacity of 16,000 mAh was selected.

        - The discharge capacity must provide a burst discharge capacity of 20C for 10 seconds, resulting in 320 Amps. The steady-state discharge rate must be of 10C, resulting in 160 Amps.
    - For the reasons listed above, the batteries used are 6S LiPo, 16,000 mAh.
- **Mission Requirement - Arm Configuration (Redundancy and Risk Mitigation)**
    - Prior to deciding what type of arm configuration would be used for the design of the drone, research was performed on the advantages and disadvantages of each configuration. This research effort has led us to the conclusion that a standard six arm configuration (hexacopter) would be the most appropriate for our needs for the following reasons:
        - Relative ease of construction and assembly when compared with other layouts (e.g. Y-arm setup, matrix, etc.)
        - Abundance of reference information available online since this type of platform is commonly used.
- **Mission Requirement - Image Processing System**
    - The system to be used for automated shape and character recognition is the CMUcam5 Pixy. It consists of an image sensor paired with a dedicated processor used for object detection. The main performance advantage provided with this system is the elimination of the need for post-processing the images on a PC.
- **Mission Requirement - Ground Control System**
    - The graphical user interface to be used during the competition is called Mission Planner. It is used to communicate with the drone via radio signal, receive telemetry data and send mission updates back to the UAV.
- **Mission Requirement - Autopilot**
    - The numerous mission tasks involving autonomous flight have led us to look for a flight controller with flight autonomy capability. The autopilot used on our UAV is the Pixhawk module from 3DRobotics. This system provides our platform with a range of possibilities. The Pixhawk module is an open source project and it is highly versatile as it is compatible with numerous platforms and

configurations. The company developing this system, 3DRobotics, has extensive experience in developing avionics controllers and as such, it was decided that their system would be the most appropriate for our system.

1.3. PROGRAMMATIC RISKS AND MITIGATION METHODS

Risk Factor	Description	Risk Level	Impact	Mitigation Method
Design and Manufacturing stage delays	Delays in the design or manufacturing phases of the project may impede on the team's ability to present a working system to the competition.	Medium	High	Platforms used in previous years for different competitions are being maintained in a valid operating condition so that they may be used as a backup solution.
Compliance with Competition Rules	The UAV and all of its systems bust be in accordance with the terms specified in the competition rules.	Low	High	Analysis and reviewing of the competition rules has been performed on several meetings early in the design process.
Legal Issues and Insurance	The UAV must be properly insured and must be legally allowed to operate in the jurisdictions in which it will fly.	Low	High	• A dedicated officer in our Executive Committee has made sure the system is compliant with the applicable jurisdiction regulations. • Matters of insurance have been dealt with very early in the process of planning our participation in the competition.
Target Recognition Software Issues	Different weather condition may alter the UAV's ability to detect and identify various targets essential in completing the objectives.	High	Medium	Testing will be performed prior to the competition with various cardboard or wood cutouts to be tested with the CMUcam5 Pixy.
Flight Test Crash	Flight tests may result in a crash that could damage some of the UAV's most critical components.	Medium	Medium	• Some of the most critical components (motors, propellers, battery) have been ordered in quantities exceeding those required, thus providing us with spare parts. • The drone used for the current-year competition was assembled entirely from new parts while maintaining the previous year drone as backup.

Image Processing Issues	The CMUcam5 Pixy is currently the system relied upon to perform the shape and character recognition. Technical issues could significantly compromise our ability to achieve several objectives during the competition.	Medium	Medium	A non-automated method for detecting shaped and characters in the images will be kept available in case the CMUcam5 Pixy fails.

In addition to the programmatic risks listed above, budget limitations also constitute uncertainty in whether the drone design will be carried out through all its phases in time for the competition. Unexpected expenditures along the manufacturing stage, if significant enough, may compromise our ability to complete the UAV. In the event that it would be foreseeable that our drone design would not be ready in time, a standard frame platform would be purchased. The electrical and software systems designed would then be integrated to the platform.

2. SYSTEM DESIGN

2.1. AIRCRAFT

The Unmanned System platform that will be used during the test flights consists of a Hexacopter. The frame used consists of the Tarot X6 platform. The frame, all six arms and the landing gear are all made from carbon fiber. The complete UAV measures 960 mm in overall length (from motor to motor) and 395 mm in overall height.

The UAS is to fly autonomously during the complete duration of the test flight, from takeoff to landing.

Figure I - Complete Assembly of Condor II

Table I - Aircraft General Dimensions

Module	Dimensions
Overall Aircraft	• Length: 960 mm • Height: 395 mm
Single Arm	• Length: 392 mm • Diameter: 25 mm
Frame Hub	• Center Plate Diameter: 328 mm • Plate Thickness: 1.5 mm
Landing Gear	• Clearance (Ground to Frame): 320 mm

Table II - Aircraft Performance Specifications

Module	
Overall Performance	• Max Speed: 15m/s • Max. Flight Time: 22 minutes • Maximum Takeoff Weight (MTOW): 8 kg • Total Weight at Takeoff: 6.5 kg
Propulsion	• RPM/Volts: 340 KV • Max. Thrust: 9 kg • Propeller Size: 16 x 5.4 CF • Battery: 16 Ah, 22.22V

2.1.1. Frame

The entire assembly of the drone, shown in figure 1 below, has a length of 960mm from motor to motor, a height of 320mm from the rails of the battery tray to the ground, and a take of weight of approximately 6.5 kg.

Figure 1 - Platform Frame Hub

Figure 2 - Complete UAS Assembly

The frame hub is composed of two 328 mm hexagonal plates, linked using spacers, screws, and hinges. The plain weave carbon fiber sheets making up the plates have a thickness of 1.5 mm, which was determined to be the optimal thickness, considering price, as well as structural soundness. To reduce overall weight, material was removed from the plates.

The arms have an outer and inner diameter of 25mm and 23mm respectively, and a length of 392mm. They are composed of plain weaved carbon fiber, providing the drone with a rigid structure for stability.

The arms are connected via the hinges mounted at the far edges of the platform, and held in place using an integral lock mechanism. Resultantly, the platform can easily be folded and transported.

The motor mounts are constructed out of high strength ABS, with a carbon fiber plate to reduce the amount of flexure while keeping the mounts as light as possible. The motor mounts are secured to the arms through the bearing force applied by tightening the bolts.

To reduce the amount of air drag as well as increase the line of sight of the image processing system, a motorized landing gear was used. It is bolted to the frame hub via four screws.

A custom gimbal mounting system for the UAS has been designed and manufactured from 3D printed parts.

2.1.2. Propulsion

The propulsion system used to move the Condor II is comprised of six 340 KV MN5208 T-Motors along with 6 AIR 40A Electronic Speed Controllers (ESC) with 16”x5.5” propellers. The decisive factors for the component selection process were reliability, overall mass of the platform, and cost.

Figure 3 - AIR 40A Electronic Speed Controller

Figure 4 - 340 KV MN5208 T-Motor

2.2. OBSTACLE AVOIDANCE

A custom interoperability client has been created by UAV Concordia to communicate with the interoperability server. Through the script feature in Mission Planner a client can be initiated simply by using the following code.

This client allows the ground station to poll the interoperability server regularly to obtain the location of all obstacles. Since the client exists within the Mission Planner script, the data returned by the interoperability server can be interpreted and directly displayed on Mission Planner. This live updating data will allow the ground station operator to be aware of all the obstacles and provide the opportunity to modify the flight plan to avoid any potential collisions.

2.3. IMAGING SYSTEM

The imaging system is a subset of the platform's overall communication system as images will need to be relayed back to the ground station. This year UAV Concordia will be using a GoPro HERO5 Black (Figure 1) for the primary imaging camera. This model offers several features that are beneficial for drone imaging such as video stabilization and noise reduction. However, the two key features used for the imaging system is GPS location tagging and WiFi support.

The Wi-Fi support will allow the onboard computer (ODROID XU4) to connect to the GoPro and retrieve images while the drone is flying. This in turn links the GoPro to UAV Concordia's Software Architecture. The onboard computer will be configured to automatically connect to the ground station computer and begin transferring images as they are captured. In the event that the connection is lost, images are stored in a queue until the onboard computer is able to re-establish the connection and resume the transfers. For more information regarding the drone to ground station connection please see section X Communications.

The second key feature, GPS location tagging, is beneficial to all image processing that occurs once the image has been transferred to the ground station. The HERO5 Black embeds the GPS coordinates of where an image was taken inside the image's meta data. This way, when a target is found within an image, the system can tell exactly where it is just by looking at the images meta data.

2.4. OBJECT DETECTION, CLASSIFICATION AND LOCALIZATION

To complete the primary objective of detecting and decoding objects while flying, UAV Concordia's system will be using TensorFlow. The TensorFlow network itself is built in C++, which is exponentially faster than Python. Python, however, is much easier to work with. This means that the TensorFlow methods, which are called in Python, are actually C++ methods. TensorFlow is an open source library that is a framework for implementing artificial neural networking. The neural networks are modelled as a weighted directed graph. Specifically, the graph is used to implement a convolutional neural network, which is a type of feedforward neural network. Additionally, TensorFlow takes advantage of graphics cards which are fast parallel processing engines and can be used for training and running neural network programs.

The method begins with an input which could be more than one dimension, in the case of a pictures, it's a big vector of numbers. Multiplying in 2D to get many pixels, each pixel is represented as a nonnegative as fixed or floating point. For grayscale 0 is black.

Each input signal, which are each distinct from one another to begin with, gets multiplied by a weight via a connection to a neuron. Additionally, a bias is added, which could be one of vector of constants. So, the signal comes in from one end, travels along the connection, gets multiplied by a weight which is associated with that connection and the outcomes get summed into a node, which is a neuron. That neuron then becomes the input into the next neuron, which has more connections coming into it. The weights themselves can be thought of as forming a decision boundary in higher dimensional space. The output is a series of 36 output units and the goal is to train the model so that one of the alphanumeric is represented as one (true) and the other is 35 are zero (false). This sort of vector is called a one-hot vector, so the model is given one-hot vectors with which to train.

Almost always there must be non-linearity after each neuron. There are the inputs, which get weighted and summed into the neuron. It is possible to end up with a huge positive or negative number. If the model implements a nonlinear function, e.g. the inverse logit function, these huge numbers would remain in the domain of the function which would then guarantee an output anywhere between zero and one. So even though it's not a linear function, the output and the neurons are monotonically related. The outputs won't be exactly zero and 1, bit they tend to be close to 0 and 1. At the start of training, however, they are completely random.

The model is trained with supervised learning. The reason it is considered is supervised is because a training set is used that has already been labeled with the desired classification. It is told the correct answer. There are a series of inputs and a series of output units where the decision comes out. During training, the desired decision is given. The model comes up with its actual output, and the difference between the desired output and the actual output is calculated. This is called the cost function. To find the local minimum of the loss function, the partial derivative of the cost function with respect to the free parameters (weights and biases) of the model is computed. The partial derivative is taken because the weights have to be analyzed one at a time. Once the partial derivative is computed, the result is the gradient of the loss function. The negative of the grad function is the steepest descent, the direction in which the weights and biases should be modified. The gradient is descended via back-propagation, which only happens at training, and is used to modify the weights of the network via an iterative process. It is undesirable to make changes to the weights too quickly, so a step size is determined that is a small fraction of the partial derivation. If the change are too big, it is possible to overshoot or cause an error somewhere else in the model. The step sizes dictates that the algorithm makes the smallest change possible in the direction of the partial derivative. The goal is to implement the smallest magnitude change which will have the greatest impact on reducing the loss function. The training process is very computationally intensive, hence why TensorFlow methods are C++ methods.

As mentioned in section X Imaging System, all images captured and transmitted to the ground station for processing will be captured by a GoPro HERO5 Black. This model supports GPS tagging images. As a result, all images processed by the ground station computers will be tagged with the exact location of where the image was taken. Therefore, when an object is detected in an image, its location can easily be determined by looking at the image's meta data.

2.5. COMMUNICATIONS

Communications between the UAV and the ground station are maintained through three wireless links, namely an analog video signal, a remote control (RC) link and a 915 MHz telemetry and control link. All antennas on the drone are installed on its underside to ensure a minimal amount of physical obstructions to the signal transmission.

- Analog Video Signal

- Remote Control (RC) Link
- 915 MHz Telemetry and Control Link.

2.6. AIR DELIVERY MECHANISM

The mechanism which will be used to accomplish the payload drop task for this competition is very simple yet effective. It is inspired by the clamps children use to pick up objects from the ground. To ensure proper grip between the clamps and the bottle, the area of the surface of contact between both components covers most of the lateral area of the bottle; the clamps will hold the bottle in a manner that will create a deflection inwards, and the surface of the clamps is designed for that purpose. Other mechanisms developed earlier proved to be too large or heavy for the purpose of this competition during test flights, explaining the simplicity of the current mechanism. Below is a figure that represents the mechanism's concept. This picture does not put into display the final version, but most important components are visible.

Figure 6: Representation of the payload drop mechanism

The mechanism was designed on a 3D CAD software and manufactured using a 3D printer. The advantage of using this technique is the weight of the material. Plastic is very light yet strong enough for the needs of this competition. The screws used to assemble the clamps on the servo however are normal metal screws.

The functioning of the mechanism is as follows. First of all, the servo will be attached to the drone for the water bottle to be oriented facing forward, with its length parallel to the ground. The reason for this orientation is to allow a more stable launch. Using air flow simulation, the least turbulence around the bottle was obtained using this launch orientation.

The bottle is installed in the clamp and held in place by a servo that applies torque to keep the clamps closed. As the drone approaches the drop location, the horizontal distance is constantly recalculated by the navigation system. When the distance is equal to the pre-calculated distance at which the bottle should be dropped, the drop procedure is initiated. The navigation system sends a signal to action the servo, causing it to open the clamps and drop the water bottle.

2.7. CYBER SECURITY

Given the fact that UAV Concordia has existed for only a small amount of time now, elements pertaining to cyber security have not been addressed in this year's design due to a lack of manpower and technical expertise on the matter. This is a design aspect that the society will address in the next academic year in the form of system upgrades.

3. TEST AND EVALUATION PLAN

3.1. DEVELOPMENTAL TESTING

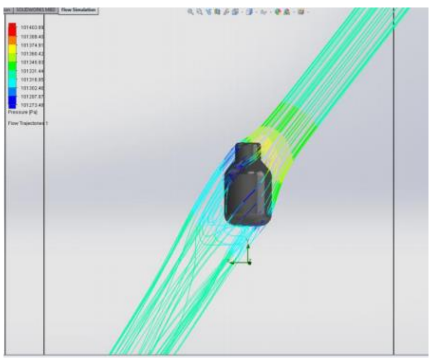
Flight tests have been performed throughout the academic year. Given that the frame and other structural elements have been carried over from last year's design, no testing was performed on those as it's capability to meet specifications has already been assessed. Systems of autonomous flight and of payload delivery have been testing by the flight operations team during test flights and results have been communicated to the relevant design teams whenever changes were necessary. The most significant changes as a result of this developmental testing affected the air delivery system, which has been designed several times to increase the accuracy of the drop but also to reduce the risk of the payload being stuck and not dropped.

3.2. INDIVIDUAL COMPONENT TESTING

3.2.1. Air Delivery Simulation

Several airflow simulations for the payload have been computed using Solidworks during the research stage of the project. The main purpose of these simulations has been to determine the influence of the wind direction on the water bottle payload. Results from the simulations have led the research team to the conclusion that the most efficient way to reduce wind turbulence was to launch the water bottle in a vertical orientation rather than a horizontal one. The data retrieved also helped the team in designing an optimal drop mechanism capable of accurate payload releases. Later on, several tests on the test field have been performed to assess the reliability of the payload release mechanism.

Shown above are visual representations of the simulations computed:



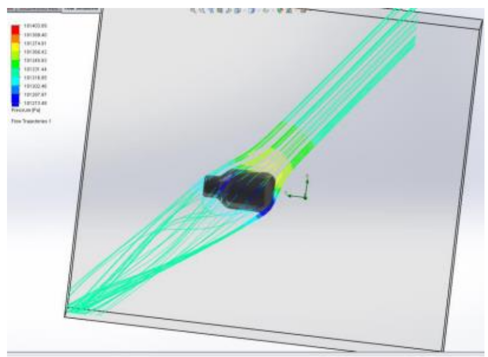


Figure 9. Original UAV Platform Designed

Figure 10. Actual Platform Frame Hub

3.3. MISSION TESTING PLAN

Mission Objective	Subtask	Threshold Achieved	Objective Achieved
Flight Time		66%(<20mins)	83.33% (< 30 min)
Autonomous Flight	Takeoff	n/a	90%
	Flight	n/a	100%
	Waypoint Navigation	100%	100%
	GCS Display Items	100%	100%
	Landing	n/a	80%
Search Area	Localization	90%	100%

	Classification (Standard Target)	100%	100%
	Classification (QRC Target)	100%	100%
	Imagery	N/A	100%
	Autonomous Search	N/A	100%
	Secret Message	N/A	95%
Autonomous Target Detection, Localization and Classification (ADLC)	Will not be attempted		
Actionable Intelligence	Actionable Intelligence	80%	70%
Off Axis Standard Target Task	Imagery	N/A	55%
	Classification	75%	70%
	Payload Autonomy	N/A	N/A
Emergent Target	In-flight Re-tasking	N/A	60%
Payload Drop	Release	100%	0%
	Drop Accuracy	100%	95%
	Bull's Eye Delivery	N/A	60%
Simulated Remote Information Center (SRIC)	Will not be attempted		
Interoperability Task	Download & Display Server Info and Time	100%	85%
	Download & Display Obstacles	N/A	N/A
	Upload Target Details	N/A	N/A

4. SAFETY, RISKS AND MITIGATIONS

Numerous test flights have been performed with the current platform during which the safety of the UAV was evaluated. Our primary focus has been to minimize the risk of any damage or injury from occurring.

4.1. DEVELOPMENTAL RISKS AND MITIGATIONS

Risk Factor	Description	Risk Level	Impact	Mitigation Method
Design and Manufacturing stage delays	Delays in the design or manufacturing phases of the project may impede on the team's ability to present a working system to the competition.	Medium	High	Previously used platforms are being maintained in a valid operating condition for use as a backup solution.
Flight Test Crash	Flight tests may result in a crash that could damage some of the UAV's most critical components.	Medium	Medium	Some of the most critical components (motors, propellers, battery) have been ordered in quantities exceeding those required, thus providing us with spare parts.

4.2. MISSION RISKS AND MITIGATIONS

Risk Factor	Description	Risk Level	Impact	Mitigation Method
Geolocating Issues	Problems in the geolocation of the targets will compromise our ability to complete crucial mission tasks.	Medium	Low	We determine GPS coordinates of the boundaries and have them before flight. Then once we have a stitched picture of the area we can calculate rough estimates of location and in terms of (x, y) based on the area and convert it to GPS coordinates.
Wi-Fi Link interferences	The Wi-Fi devices may interfere with either the pilot's manual controller or the	Low	Low	With our first tests at 2.4GHz, if we find unacceptable levels of interference, we will test at 5GHz. If 5GHz interferes with the FPV video link, we will consider the which feature is most desirable, since the Wi-Fi link is a non-essential feature.

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4.3. OPERATIONAL RISKS AND MITIGATIONS

Driver Power Failure	Medium	Pilot can no longer control UAV	The autopilot will bring the aircraft to land for inspection.
FPV Camera Failure	Low	Loss of Direction	The pilot will rely on the camera used for image processing. If replacement of the FPV is judged to be necessary, the drone will be returned and the camera replaced.
Motors Malfunction	Low	Flight Stability Compromised	If one or more motors are compromised the thrust stick will manually be turned to off to place the drone in free fall. Once approaching the ground, a swift shift from high to low thrust for a soft landing
Data Link Failure due to antenna malfunction	Low	Loss of orientation w/ respect to mapped area	The pilot will land the UAV and the failure will be examined. The antenna will be replaced.
Controller battery loss	Medium	Unpredictable behavior of UAV	To avoid unpredictable behavior the autopilot will have a built-in function to land connection to the controller is lost.
Battery Fire during Flight	Medium	Risk of physical injury and damage to UAS	The battery enclosure mitigates the possible damage caused to the electrical components by limiting their exposure to a potential fire. A fire extinguisher available on hand will be used in case of an emergency landing.

4.4. SAFETY PRECAUTIONS

Prior to the test flights, safety precautions have been taken to reduce the risks of any system malfunction. These safety measures included:

- On-site safety inspection is performed to ensure all safety standards and requirements are met.
- Visual inspection of the structural components of the platform. The detection of visible flaws would lead to the cancelling of the test flight to eliminate any chance of catastrophic mechanical failure during flight.
- Inspection of all batteries used for any signs of damage and ensuring they are properly charged. Lithium-polymer batteries impose a fire hazard if they are damaged or are not properly charged.
- Inspection and testing of release mechanisms for the payload systems.

5. CONCLUSIONS

This technical journal presents an overview of the efforts deployed by the students from the UAV Concordia team. Throughout the last year, a great deal of learning was necessary for many of the team members to develop the different systems present on our platform. The most significant tasks faced by our team included the integration of autonomous target detection capabilities and the designing of a reliable payload drop mechanism. Safety has also been a concern throughout the assembly and testing phases of this project as seen with the implementation of various safety procedures. In all, the completion of all primary and secondary tasks has been our main objective and this has guided our team's dedication in completing the UAV.