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AUVSI Team

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BRONCOS

CAL POLY POMONA

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Abstract

With this being the Sixth year that Cal Poly Pomona has participated in the AUVSI's SUAS Competition, the team fully expects to improve on the successes of the previous years. This year, the waypoint navigation, search area, off-axis target, actionable intelligence, emergent target, air drop, interoperability, and sense, detect, and avoid tasks will be attempted. A new airframe will be implemented from last year's airframe, but a new datalink and image recognition sub-system was integrated into the system to improve the overall system performance. A combination of simulations and flight tests were conducted to prove the performance of all the system elements, giving the team the assurance that the system will successfully perform at the 2016 Competition.

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1.0 Mission Requirements Analysis

1.1 Requirements Analysis

From the start of the design process, mission requirements guided the development of the autonomous aerial system and its subsystems. The primary autonomous flight, search area tasks and onboard image processing drove the selection of a bigger fixed-wing system in order to meet the flight time and payload parameters required. The off-axis target task necessitated a gimbaled camera system. The radio frequency system was drove the creation of a non-conflicting frequency system between autopilot telemetry, manual control, and imaging data. The air-drop task led to the inclusion of a water bottle drop system and the necessary code development to operate it. The interoperability and sense, detect, and avoid tasks (SDA) required the selection of an open source ground station program. These tasks will be completed in the required one hour mission time.

1.2 Design Rationale

1.2.1 Aircraft Subsystem

The aircraft subsystem consists of a modified Hanger Nine Valiant airplane. This model was chosen due to the airframe being larger and increased payload from last year's model. An Evolution 33cc gas engine was chosen over an electric motor because of the increased flight time and being capable of using more of the payload from eliminating the need for batteries for the motor.

1.2.2 Autopilot Subsystem

The autopilot subsystem consists of a Pixhaxk (PX4) autopilot which uses Arduplane software. This was chosen as an improvement to last year's Ardupilot Mega 2.6 as well as the multi-function capabilities of the open source software. The airplane is equipped with a GPS receiver and a 915 MHz radio and antenna to transmit telemetry to the Ground Control Station (GCS). The GCS consists of a laptop dedicated to running Mission Planner software. A 2.4 GHz radio is used to allow the safety pilot to take over at any time to ensure a safe environment.

1.2.3 Payload Subsystem

The payload system consists of two subsystems: imagery and air-drop. The imagery subsystem consists of a gimbaled camera, and on-board processor to process the images and a 5.8 GHz transmitter and antenna to send the images to the GCS. The air-drop system is composed of a custom water bottle drops mechanism interfaced with the PX4.

1.3 Expected Performance

The new airframe model and engine was chosen for and improvement to payload capacity as well as flight time from last year's model. The autopilot systems serves as an improvement considering the age of previous year's model as well as increased performance. The platform is expected to meet the majority of the threshold requirements of the previously mentioned tasks during competition. This is based off the four test flights with the old airframe as well as six(expected) flights with the new airframe model. The imaging system has undergone testing in and out of flight and is expected to successfully meet the require performance goals. Autonomous image processing system are in testing but are expected to meet requirements outlined in competition. The software for interoperability has undergone numerous tests and has proven to reliably upload and download the appropriate information at the objective rate of 10 Hz without exceeding 15 Hz or falling below 8 Hz. The software for the stationary target portion of the SDA task has been tested and has proven to meet the objectives of autonomously rerouting the UAS around the obstacles. Moving targets will not be attempted this year. Simulated Remote Information Center (SRIC) is currently going through testing and formatting and is expected to perform its objective task by the competition.

Table 1.3: Expected Performance

Requirement #	Parameter	Threshold	Objective
R7.1.1	Takeoff	**Requirement Met**	**Testing**
R7.1.2	Flight	**Requirement Met**	**Requirement Met**
R7.1.3	Waypoint Navigation	**Requirement Met**	**Requirement Met**
R7.1.4	Landing	**Requirement Met**	**Testing**
R7.1.5	Ground Station	**Requirement Met**	**Requirement Met**
R7.2	Search Area	**Requirement Met**	**Testing**
R7.3	ADLC	**Testing**	**Testing**
R7.4	Actionable Intelligence	**Requirement Met**	**Testing**
R7.5	Off-Axis Target	**Testing**	**Testing**
R7.6	Emergent Target	**Requirement Met**	**Testing**
R7.7	Air-Drop	**Requirement Met**	**Testing**
R7.8	SRIC	**N/A**	**Testing**
R7.9	Interoperability	**Requirement Met**	**Requirement Met**
R7.10	Stationary SDA	**Testing**	**Testing**

1.4 Programmatic Risks

A major programmatic risk was difficulty getting all members to meet at one time. This came from every member being a full time undergraduate student and having busy and conflicting schedules. This risks also caused another risk of not completing the tasks by the deadline of the competition. These risks were mitigated by having a meeting time on the weekend where most members where free most of the time. Furthermore, the team was divided into sub teams in order to allow more flexibility in scheduling the meeting times. For the risk of not completing tasks by the deadline, this was mitigated by creating deadlines before the real deadlines.

Another programmatic risk that the team faced this year was being unable to fly the new airframe due to getting permission and proof that the aircraft was safe to fly. This caused the team to wait to fly the new airframes until the necessary paperwork was filled out and approved at the team's test area.

2.0 UAS Design

2.1 Aircraft Design

2.1.1 Airframe

The airframe subsystem chosen for this year's competition is the Hangar 9 Valiant. The Electric Powered Sig Cadet that has was used in previous years had reached its limitations in regards to payload capacity and flight time. In order to ensure that the capabilities of the systems could be expanded and improved, an entirely new airframe was needed. The Hangar 9 Valiant in conjunction with a 33cc gas motor, proved to be the most appropriate choice as it provides a larger internal area for hardware, greater payload capacity, longer flight time, and overall easier accessibility to internal components. Using an airframe that could accommodate a gas powered engine allows for greater mission endurance. The structure of the stock airframe was modified in order to optimize the layout of the hardware systems. These modifications include a servo mounting plate installed in the rear tail section of the plane. This allows the servos that control the empennage control surfaces to be positioned away from the front of the plane making room for our hardware sub-systems. The polyester film above the servo plate was removed and replaced with a custom made clear plexiglass hatch door for easy accessibility and viewing to the internal components. A second mounting plate was also installed in the center section of the fuselage to mount the camera gimbal. This mount was placed so that the gimbal and a majority of the camera remain within the plane while the lens extends below the floor of the fuselage and as a result, the polyester film along the bottom of the plane was removed.

Figure 2.1.1: The Hanger 9 Valiant Airframe

2.1.2 Power System

A three cell lithium polymer battery is used as the power source for the control servos and the Pixhawk autopilot. This battery is connected to a 5 volt output dc to dc buck step down voltage converter which steps the battery voltage down to a 5 volt operating voltage. An externally mounted switch is incorporated into the circuit between the power supply and the Pixhawk to allow for easy power reset of the Pixhawk. This was chosen as the power supply to ensure that it could meet the instantaneous current draw of the all servos.

Initially the power was delivered to the servos from the Pixhawk's power rail; however, this method did not allow enough current to power all the servos. To fix this we split the power and neutral lines from the signal line on each servo and bypassed the Pixhawk to draw power straight from the buck converter. This fixed all previous irregularities that we had encountered when powering the servos through the Pixhawk.

A 3 cell lithium polymer battery was used to power the camera and Bullet transmitter. Both these require 12 to 24 volts for operation. However, the camera was not at top performance so a 5 cell 18.5 volt battery is now the power source for these components. With a 24 volt input voltage the camera is able to perform at its highest performance level.

A 2 cell lithium polymer battery is connected to a spark plug ignition coil which steps up the voltage to the spark plug. An issue with consistency as well as lengthy set up time when connecting the electronics from the wings to the body of the plane where every time the wings needed to be attached or detached. To speed up this process and to ensure the consistency in the aileron servos, flap servos and Pitot tube connections, a quick connect was installed between the wing and fuselage. A VGA connector were selected because they provide 15 pins to connect all the servos requiring 6 pins total for both the aileron and the flap servos. The connecters were attached so that they would line up perfectly when connecting the wing. A USB connection is used to connect the Pitot tube in a similar fashion.

A 3 cell lithium polymer battery is used to power the Intel NUC onboard computer. This was achieved through the use of a dc to dc power supply that supplies 19 volts to the NUC. This arrangement with a 3 cell Lithium polymer ensures sufficient power to operate the NUC for the extent of mission the mission operations.

2.2 Autopilot

For this year's competition the Pixhawk (PX4) was chosen due to old age of previous year's Ardupilot Mega 2.6 (APM) and its performance decreasing. The PX4 was chosen for many of the same reasons that the APM was chosen in previous years in that it is open-source and the PX4 is close to the APM in design. This eliminates learning a completely different system by choosing and system close to APM.

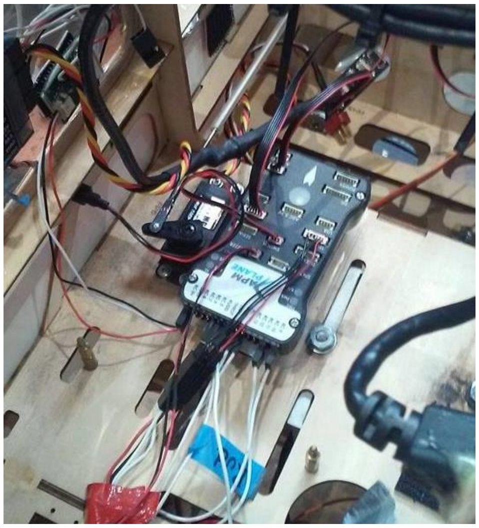

Figure 2.2.1: The Pixhawk Autopilot system

2.3 Data Link Design

2.3.1 Radio Frequencies

The UAS has three radio frequency (RF) sources for its data link. These three sources are for the manual control of the airplane, telemetry, and video. The manual control for the aircraft is on a 2.4GHz frequency to insure no interference would occur for the safety pilot's control. The telemetry communication between the autopilot and the ground station is on a 915 MHz frequency. The video is streamed over Wi-Fi using a 5.8 GHz frequency. All of the radios use frequency hopping spread spectrum technology to mitigate risk of interference.

2.3.2 Antenna Selection

The circularly polarized antennas were again chosen for both the 5.8 GHz frequency and 915MHz frequency. As a result of the selecting directional antennas for the ground station, a tracking system was necessary to maintain a strong connection for the imagery and telemetry. This system will be described in more detail in Section 2.5.5 of this paper.

2.3.3 RF Transmitter Design

To achieve mission goals, two subsystems of communication with the autopilot; an onboard computer using an FTDI cable interface for onboard telemetry data and a XBee Pro 900MHz radios for telemetry data between the autopilot and the ground station. The universal asynchronous receiver/transmitter (UART) port was chosen as the method for communications between the onboard computer and the autopilot. There were 2 valid options when designing this system, a USB to micro USB connection or a UART port to an FTDI usb cable connection between the autopilot and the onboard computer. Research showed that with our particular autopilot many users had reported connection issues with the USB to microUSB method and it was known to disconnect midflight so this method was too unreliable for our requirements. The UART to an FTDI USB cable was chosen because it was quick, reliable, and heavily tested by many users. The system uses a standard UART connecter which passes through an FTDI chip that allows for a USB interface between the autopilot and the onboard computer. This system provides minimally delayed flight data to the onboard computer where it is used for the water bottle drop calculations and for the autonomous image recognition task.

The XBee Pro 900MHz radios fit our requirements of being cost effective, reliable, FCC approved, and capable of transmitting the required bandwidth over a long distance. The onboard system consists of a SparkFun XBee Explorer used to interface between the XBee radio and the autopilot which uses the UART protocol for communication. The ground station consists of a SparkFun XBee Explorer USB used to interface with XBee radio and the ground station computer through a USB connection. The radios interface between each other on the 900MHz bandwidth and the connection is secured using AES encryption for added safety and security. During the assembly of the system it was discovered that the peak to peak voltage of the signal received by the onboard XBee radio was too low to be understood by the XBee internal logic. To resolve this issue an amplifier was designed and implemented to amplify the signal coming from the autopilot to above the required 3.3V peak to peak.

2.4 Payload Design

The payload on the airplane consists of the camera system with its accompanying gimbal system, along with a payload drop system and on board processing system.

2.4.1 Camera

The camera being used is the Point Grey FL3-GE-2854C-C (flea3) with a Fujinon lens, which has the capability of having a focal length between 3.8mm and 13mm. The lens was chosen to focus on targets at 150 feet because this is the flight altitude chosen for the search area tasks. This camera was used at last year's competition and was chosen for this year's competition because of its compact size and image quality. The size of the camera being used is 29x29x30 mm and it weighs 38 grams. It has the potential to have a 1928 x 1448 image at 15 FPS using a Sony ICX687 CCD, 1/1.8", 3.69 µm. The sensor uses global shutter to avoid distorted images while flying. The FLEA3 uses Gigabit Ethernet to transfer data and sends the image frames to the ground station using the M5 bullet. Last year, an onboard computer was not used to attempt to automatically detect targets by processing the video onboard. This year the onboard processor was integrated onto the new airframe and code was written for autonomous detection. This code was written in a way where it could be integrated into either a ground control station or the plane's onboard computer, as a precaution to not enough testing for the onboard computer.

2.4.2 Camera Gimbal

The two axis camera gimbal developed last year was used to achieve nadir imagery. This is extremely important for the case that the airplane is banking or changing altitude above a target. The gimbal has the capability of rotating ±30 degrees for roll and ±20 degrees for pitch.

2.4.3 Payload Drop

The water drop program works through the ground station and will communicate with the plane to assess the most optimal course of action to assure a successful drop. As the code is mostly stand alone with some manual actions, it was decided that C# will be used, as it was capable of accomplishing the plan set worth and was the most understood by the coder. The program itself is broken down into two parts. A Pre-flight section that requires the manual input of the target's GPS location, as well as the GPS location of the waypoint that leads into drop approach. The other half of the code runs while the plane is mid-flight. Throughout the course of the plane's run, the code averages the current wind speed and directions, as well as, estimates what they will be when the payload is dropped. With these estimations, it then predicts the amount of displacement the bottle will have in both the direction the plane is traveling and in the direction lateral to the plane. As there is no method of correcting the amount of the displacement orthogonal to the plane with timing alone, the program, using the pre-flight inputs, instructs the person at the ground station how much to adjust the start of the approach and end of the approach waypoints by, as to correct for those movements. Then, once the plane is in its approach and reaches the optimal, calculated drop GPS coordinates, the program will automatically initiate the water drop sequence.

2.5 Ground Control Station

The Ground Control Station (GCS) consists of an antenna tracking system and four laptop computers. The four computers: two Mission Planner computers, an image processing computer and a backup computer.

2.5.1 Primary Mission Planner computer

The objective of this computer is to use the Mission Planner software as the main connection between the airplane and the GCS. The Mission Planner will have a predetermined flight mission already loaded which will show where the airplane will fly. The main interface of the Mission Planner software, as shown in Figure 2.5-1, will provide the information requested, which includes: altitude, speed, heading, no fly zones and obstacles.

Figure 2.5-1: Picture of Mission Planner Interface with a Flight Mission (Red is the Boundary for the No Fly Zone)

This information will be relayed to the primary image processing computer to provide the airplane's telemetry which is required for the target information. This computer will also connect to the sUAS interoperability server to collect the information provided by the server, which includes the obstacle locations. The team member at this station will be responsible for watching the airplane's path for smooth flight as well as loading new waypoints for various tasks such as the egg drop or the emergent target.

2.5.2 Secondary Mission Planner Computer

The main objective of this computer is to assist the primary Mission Planner computer in re-tasking for the emergent target and general search area. When the information of the emergent target becomes available, the secondary computer will then create a new waypoint in the Mission Planner software as well as a new flight path and then transmit the new Mission Planner file to the primary computer. Communication between members manning the primary and secondary Mission Planner is important because they will exchange information on the emergent target and new flight paths. Communication with the primary camera computer is also important because the primary imaging computer will inform the secondary Mission Planner operator where to get the most optimal picture of the emergent target and general search area.

2.5.3 Imaging Computer

The primary imaging computer takes the autonomous processed image from the onboard and classifies the target image. This serves as a double check to see if the images selected from the on board computer is a target image as well giving the target characteristics to satisfy the section 7.2 objectives.

2.5.4 Backup Computer

The backup computer will be used if the autonomous on board processing does not work and it is needed to be put on the computer in the GCS. This would make the processing of the images done on the backup computer rather than on the plane. This would communicate with the imaging computer with giving the target images for classification.

2.5.5 Airplane Tracking Antenna System

Due to the selection of directional antennas for the GCS, a tracking system was necessary to maintain a strong connection for the imagery and telemetry. From last year's decided to build a tracker, last year's tracker has been fixed and improved. A patch antenna replaced the helical antenna used last year as its field of view was too narrow and broke being shipped to competition. The custom tracker includes a slip ring, continuous rotation servo, metal geared servo for the tilt motion, magnetometer, a Pixhawk autopilot and a laptop computer. The Continuous rotation servo and slip ring allows the tracker to rotate as many times as needed during a mission. The magnetometer was necessary to help utilize the continuous servo and to develop a closed-loop control system for the pan. The tilt portion of the tracker assembly used a servo with a 120 degree rotation and has a built-in potentiometer for the measurement of the tilt angle based on the pulse width modulation. With the Pixhawk convenience with mission planner, using it as part of the antenna tracking system made it easy to connect to the plane.

2.6 Data Processing Design

2.6.1 Image Processing

The camera software uses windows forms GUI and uses EmguCV for image processing. The software is split into two sections, manual detection and autonomous detection.

2.6.1.1 Manual Processing

In manual detection the user is able to watch video stream as it is transmitted to the ground. The user is capable of stopping the stream, fast forwarding, rewinding, or moving or traversing the images 1 image at a time. If the user sees the target they can input the target characteristics and save the data to the submission folder.

2.6.1.2 Autonomous Processing

In autonomous mode the software is cable of autonomous target detection, localization, and classification. To achieve this, the program has 3 key phases: training, detection, and localization.

Training is performed by displaying various shapes and characters in front of a camera and finding the contours of the image. Once the contours are found they are displayed to the user who has to define the contour. The named contours are saved to a template and later used to compare and identify shapes and alphanumeric characters for identification.

Detection is done using contour analysis. Contour analysis was chosen because it reduces the number of attributes that need to be compared, it has a lower computational cost and a lower algorithmic complexity than other solutions researched, and it solves the main problems of pattern recognition: transposition, turn, and rescaling. The contour is defined using a sequence of vectors made of complex numbers going clockwise until it reaches the starting point. This is done because the mathematical properties of the complex vectors make working with them much simpler. Each image is smoothed, blurred, and finally converted to binary. Contours are extracted and filtered based on size. An autocorrelation function is used to match possible detections and narrow down the number of searches required. It is further accelerated using wavelet convolution. Once we get a list of matches we use an intercorrelation function to make a definitive match between two contours. This provides for a result that is not affected by the contour starting location, transposition, rotation, or the scaling of a contour and if the contours are identical they will have maximum unity. It also makes it easy to calculate the angle of rotation of the contour using a tangent function. The primary search is for a shape, once we find a shape we perform the same contour process, but we only search inside the shape for an alphanumeric character. To prevent duplication we check if the same image has been detected previously. If it has then we do not consider that to be a new target and instead we confirm the characteristic found and store the data in a list for future comparison.

Localization is achieved by attaching a GPS location to each image. Once a target is found the associated GPS location is used to localize it. The plane heading is also attached to the image and we are able to find the angle of rotation of the contour by modifying the intercorrelation function. Using the contour angle along with a heading attached to the image we can find the letter's orientation. We convert the image to the HSV color space and get an average value for the color inside the contours to find the colors of the shape and alphanumeric character.

2.6.2 Telemetry Processing

The telemetry processing was amended to the Mission Planner software. The software retrieves flight information from a communication link between the Mission Planner and the APM called Mavlink. This information, which is received at 10 Hz, is saved as a string and is parsed for: latitude, longitude, altitude, airspeed, and heading. The parsed data is used in six tasks: the primary objective, actionable intelligence, emergent target, payload drop, interoperability, and Sense, Detect, and Avoid (SDA). To achieve this, the retrieved data is first saved to a text file in a shared folder. The primary image processing computer then requests the information from the file so that the telemetry can be associated with an image. The data is also sent to the interoperability server and the SDA software. Interoperability and SDA are discussed further in sections 2.6.3 and 2.6.4, respectively

2.6.3 Interoperability

The interoperability program works through Mission Planner and the Web Server that is provided during the competition to upload and download information to and from each. It was decided that the code needs to be written in C# in order to properly communicate information to and from the Mission Planner software. The program is split into three parts. The first part of the program runs requests and functions that are not needed to be updated at 10 Hz. Those requests and functions include the login Post request to the Web Server and the Server Information Get request. In order to ensure that all of the requests work properly, the login request is saved into a cookie. Each time a request is made, the cookie is called for the request to be made. The second part of the program includes the requests to receive obstacle information and to upload UAS telemetry data at 10 Hz. The program acquires the UAS telemetry information from the Mission Planner and then uploads that information to the server at 10 Hz to meet the Objective Requirement given in the section 7.9 of the Competition Rules. The received obstacle information is parsed from the string into doubles and uses in the obstacle avoidance part of the program. The final part of the program uploads the located target image with its corresponding information to the server. This part can be independently activated though a separate button on the user interface.

2.6.4 Sense, Detect, and Avoid

The first task performed by the SDA software is to obtain the processed data from Mavlink and the interoperability server to determine the information about the airplane and stationary. The software then checks if the waypoint path loaded intersects with any of the stationary obstacles. If it is determined that the airplane will collide with the any of the stationary obstacles, the software will create a new path around those obstacles. This software updates its calculations at 10 Hz to account for the constantly moving obstacles.

2.6.5 Simulated Remote Information Center (SRIC)

The SRIC program is still currently being developed and will be programmed in C#. The SRIC program consists of a function that will run a script followed by function that can download, create a text file, and then upload the text file. The SSID, username, and password will be saved into the computer during the setup time. Alternative methods are currently being researched. Methods for also starting the program remotely from the ground station are also being researched. The script that will be run consists of Microsoft Windows command prompt commands that will connect to a saved network. The script retries upon failure to connect.

2.7 Mission Planning

The primary mission plans are premade and correspond to the locations of the waypoint navigation, search area, off-axis target, and payload drop. There are two premade paths created for takeoff, landing, payload drop, and off-axis target. These two paths are meant for specific wind conditions. The primary imaging operator will also communicate with the primary and secondary mission planning operators. This will be done for any necessary changes to the existing paths. This may be necessary for capturing better imaging results. The whole flight mission is shown as a flow chart in Figure 2.7-1.

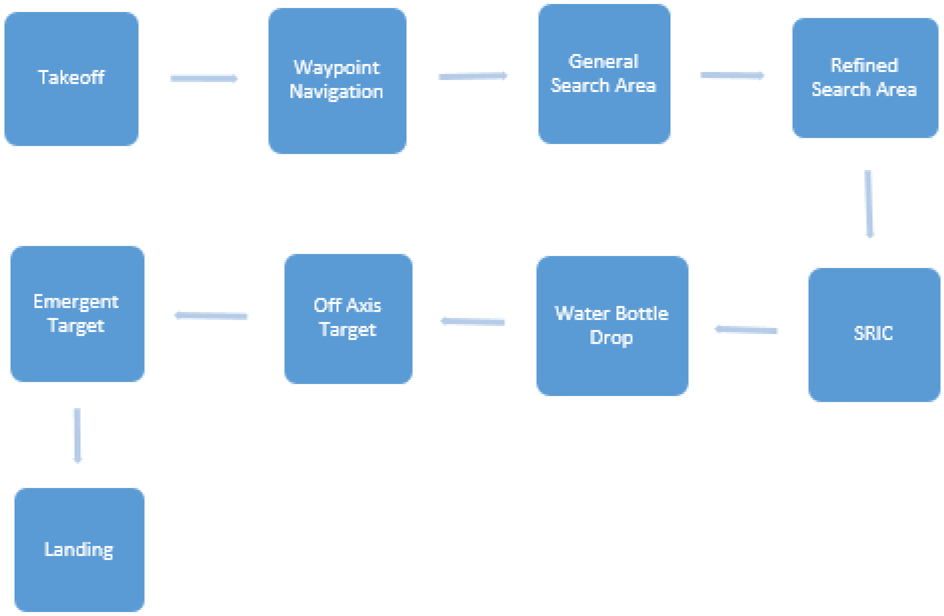

Figure 2.7-1: A Flowchart of the Logic that will be used during the Mission

At the beginning of the mission, the takeoff path will be loaded on to the Mission Planner and the airplane. Due to unknown wind conditions, the team has created two different flight plans for takeoff based on different wind conditions. After the airplane has finished its takeoff and waypoint navigation phase, the general search area plan will be loaded on to the Mission Planner. The general search area flight plan consists of doing an overlapping grid over the designated search area, as shown in Figure 2.7-2. This flight plan was decided due to the less stressful turns on the airplane when compared to starting from the edge of the boundaries and then circling into the middle of the search area. Another benefit to the overlapping grid is that it covers more ground faster when compared to a pattern of flying back and forth from one edge to the other edge in straight lines.

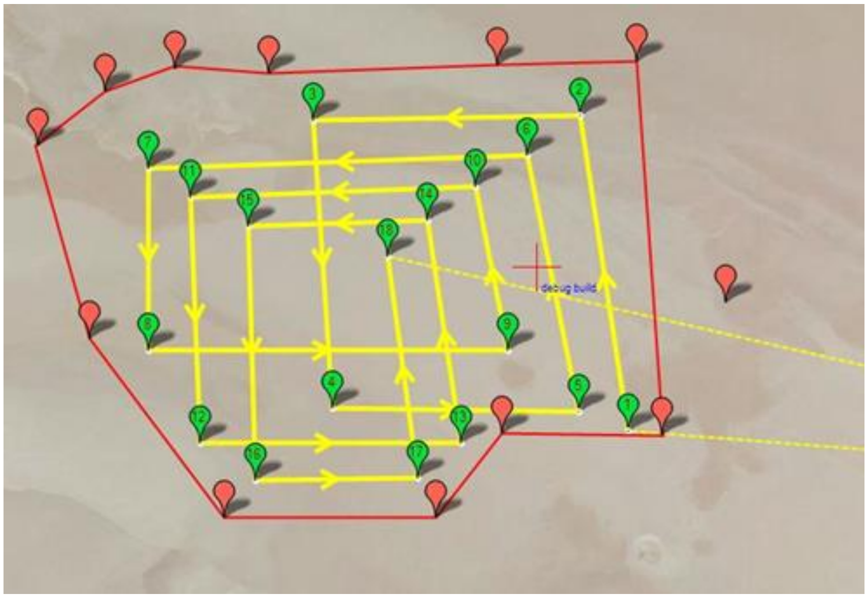

Figure 2.7-2: Example of Overlapping Grid

After the general search plan is done, the primary imaging operator will communicate with the Mission Planner operator about modifying the search area, if necessary. If time permits, a better search pattern will be created. After the general search area is completed, the SRIC coordination will be given and the location will be uploaded and the plane will fly to the location and loiter until the objective is complete. Once SRIC is completed, the off-axis target and drop path will be uploaded to the airplane. As stated above, due to unknown wind conditions, the team has created two flight paths for the egg drop mission to optimize the accuracy. As part of the requirements, the flight path will take the airplane up to 400 feet above the MSL and complete the payload drop. After the airplane descends to 150 feet above the MSL, the UAS will perform the off-axis target task. After the payload drop and off-axis target path is completed, the emergent target flight plan will be uploaded to mission planner. Due to the emergent target location are is given at the time of takeoff, the secondary Mission Planner operator will be creating a flight path to best fit the search area and last known location of the target. The pattern used will be the overlapping grid, similar to the general search area, but modified to make it convenient for the search area given. Once the emergent target is found, the airplane will load one of the landing paths depending on the location of the airplane after finding the emergent target.

3.0 Testing and Evaluation

3.1 Mission Task Performance

3.1.1 Interoperability Performance

In order to test the interoperability software, a Django web server was created using Virtual Box on one computer. A separate computer with the Mission Planner and the interoperability code connects to the server to test the validity of the program. After testing the program many times, it is found that the program is reliable in achieving a download and display between 8 Hz and 15 Hz as required in Section 7.9 of the Competition Rules.

3.1.2 Sense, Detect, and Avoid Performance

The portion of the SDA software that was associated with the stationary obstacles was tested thoroughly by uploading waypoint missions to the Mission Planner software and the airplane. The stationary obstacles were then determined from the interoperability server to allow for testing. Tests were done to verify if the software would successfully avoid various situations. The first situation tested was a single obstacle and a two waypoint path that crossed the obstacle. Once this simple test was verified, a test was done with multiple overlapping obstacles. This too resulted in successful avoidance. Finally, stationary avoidance was tested by having multiple waypoints created inside the obstacles. This last test resulted in successful avoidance as well.

After doing many tests to fix the SDA for moving obstacles, it was decided that the code would be taken out due to not being able to fix it and putting the team's time into other objectives.

3.1.3 Imaging Software

Due to the variety of issues that can occur during flight, the imaging software underwent extensive testing and the program was designed with redundancy in mind. At every stage of the design and programming, it was tested for possible failures. The goal was to develop a program that was stable and reliable during unforeseen events. After completion of the program, it went through an initial testing phase to confirm that the software acted as intended. A mockup stationary test was setup where all the elements of the flight were present. The test was initiated as it would be during flight, and each section of the software that was discussed in 2.6.1 was tested. Once this was complete, the code was tested to see how it handles interruptions and the software was terminated in the middle of the video streaming and restarted. Upon its restart, the code continued where it left off as intended. It was also tested for the loss of video stream. Upon the loss of video, the code notified the user of an issue and went to an outer menu where it waited for the user to reinitiate a video stream. During the testing phase, when the code was shut down to save the text file, an issue was encountered where a part of the data was lost. The issue was fixed by backing up all the saved data before any alterations are attempted of the data. This solved the issue of data loss, and added increased safety in case the main save file is corrupted.

3.2 Payload System Performance

3.2.1 Camera

The FLEA3 camera on board the airplane is capable of recording at 15fps in 1440p. However, the size of the video stream oversaturates the M5 Bullet Wi-Fi data transmission capability of 100 megabits per second and causes significant issues. At this resolution, connectivity issues, frame rate issues, and a significant increase to the delay of the video stream were encountered. To avoid these issues, the camera resolution was reduced to 480p at 10 fps. The camera was set to transfer a RAW 8 image, which was found to be a smaller image size than the other available formats. With these settings, the M5 bullet is transferring about 72 megabits per second. The M5 bullet is rated at a transfer speed of 100+ megabits per second, but this was not observed in real world tests. The tests showed a bandwidth limit of about 72 megabits per second, which resulted in a resolution and frame rate that is satisfactory for accomplishing the mission tasks.

3.2.3 Payload Drop

The payload drop system has completed five successful drop tests to date with no mishaps. The drops were simulated by holding the aircraft seven feet off the ground and manually triggering the drop mechanism. The mechanism was been tested by both physically moving the release servo and by computer command. The bottle and ribbon successfully cleared the launch device without being caught on the release mechanism.

3.3 Autopilot System performance

This year, four flight tests were conducted on the previous airframe to test the camera system, new autopilot system, waypoint navigation and interoperability. The reason the old airframe was used was the new autopilot system needed to be tested to prove its functionality. Another reason was to fix all bugs in the code from last year's competition and the team wanted as little changes to the environment while troubleshooting the code. Due to paperwork needed to approve the new airframe, testing on the new airframe has been limited. But recent approval of the new airframe, will allow testing before the start of the competition. It is expected to test the handling qualities as well as collecting data for the autopilot system. A full mockup of the competition is also expected to work on communication skills as well as making sure all components including the airframe and payload systems work smoothly and efficiently.

3.4 Overall Performance

The subsystem testing and full mock up system testing has given evidence that the UAS will be successful at its expected mission of autonomous flight, search area, actionable intelligence, off-axis target, emergent target, air-drop, interoperability, and SDA tasks. The imaging system has been built with redundancies and was tested thoroughly with success. Interoperability was extremely successful and has provided the team with great confidence for this task. The stationary SDA has been tested many times with many successes.

4.0 Safety

4.1 Operational Safety

Allowances for safety are made at every step of flight operations. A checklist is followed prior to each flight in order to verify the operation of all critical systems. Safety pilot, GCS operators, and ground crew work in conjunction to ensure that all functions of the system are checked. The checked tasks include: Checking and recording the voltages of all batteries and safety of battery mounting, inspection of all the servos, GPS, and communications wiring and connections, Powering up the aircraft system and radio and verifying telemetry connection to aircraft, checking all sensor outputs, including the accelerometers, voltmeter, ammeter, and sonar and checking all control surfaces and the throttle response

If a component fails to pass a check, the flight is suspended until the problem can be determined and remedied. A safety pilot and observer are always present to maintain line of sight with the airplane and take over the control in the case of a malfunction. They both stay in constant contact with the GCS operators to ensure that the aircraft is monitored at all stages of the mission.

4.2 System Safety

The system's safety methodology is based on redundant subsystems to ensure that the aircraft never poses a threat to personnel or property. The flight controls, autopilot, and payload subsystems all have their own dedicated batteries. This ensures that the loss of one electrical subsystem does not cascade throughout the entire UAS. An onboard voltage and current sensor relays information on flight battery status to the GCS. The autopilot telemetry frequency is separate from the safety pilot's radio control frequency. This prevents the failure of both autopilot and telemetry in the event of RF interference. In the event that both the autopilot GCS and the safety pilot cannot communicate with the aircraft, the autopilot is programmed to loiter until connection is reestablished. If this does not occur in a predetermined time period, a failsafe is triggered where the aircraft will immediately spiral down to the ground in order to prevent damage to personnel or property. There are two ways that the flight termination failsafe can be triggered. At any time, the autopilot operator can manually trigger an abort that will send a failsafe command to the aircraft. Alternatively, if the autopilot has lost its telemetry link with the ground for more than 20 seconds, it will automatically trigger the failsafe. This ensures that the flight can be terminated in a safe way in all possible scenarios.

4.3 Risks and Mitigation

Risk	Mitigation method
Loss of command and control link	Have the safety pilot immediately take over and attempt to establish communications. Alert bystanders of situation. If communications cannot be reestablished, have the safety pilot land the airplane. If neither option can be done, allow the aircraft to timeout and trigger its failsafe.
Loss of position or line of sight	Command the autopilot to loiter until line of sight can be reestablished. Alert bystanders of situation. If line of sight cannot be reestablished, command the failsafe condition to minimize potential damage to personnel or property.
Unresponsive flight controls	Command the autopilot to loiter until problem can be resolved. Alert bystanders of situation. If the problem cannot be resolved, trigger the failsafe command to bring down the airplane safely.
Loss of propulsion	Have the safety pilot take over and attempt to safely land the airplane.
Loss of electrical power	All personnel in the area will be alerted to the loss of control of the aircraft, any attempt to reestablish control with be made.
Ground control station failure	Immediately have the safety pilot take over and land the aircraft.

5.0 Conclusion

The UAS is expected to successfully complete the threshold requirements for waypoint navigation, search area, actionable intelligence, off-axis target, air drop, emergent target, interoperability, and SDA tasks. These will be completed mainly by using a Valiant 9 airframe, a Pixhawk autopilot, gimbaled Point Grey FLEA3 camera, and a custom built air drop mechanism. All components of the system were extensively tested both individually in bench tests and as part of the overall system in flight tests. Considerations for safety, such as redundancy and isolated power supplies were integrated into the system to migrate risks during operation. Altogether, this leads the team to the conclusion that the system will perform as expected during the Competition.

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