California State Polytechnic University, Pomona

AUVSI Team

2015 Student UAS Competition

Technical Journal Paper

BRONCOS
CAL POLY POMONA

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Abstract

With this being the fifth 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. The airframe will be returning from last year, 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 2015 Competition.

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1.0 Mission Requirements Analysis

1.1 Requirements Analysis

From the beginning of the design process, the mission requirements guided the development of the autonomous aerial system and its subsystems. The primary autonomous flight and search area tasks drove the selection of a fixed-wing system in order to meet the flight time and payload parameters required. The actionable intelligence and emergent target tasks led to the selection of an off-board data transmission and processing architecture. The off-axis target task necessitated a gimbaled camera system. The radio frequency system was driven by creating non -conflicting frequencies between autopilot telemetry, manual control, and imaging data. The air-drop task led to the inclusion of an egg 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 Sig Kadet Senior II model airplane. This model was chosen due to familiarity with the operation and flight characteristics of the airframe, as well as commonality with other Cal Poly Pomona aircraft projects. An electric motor was chosen over a gas option to minimize vibrations on the aircraft. Modifications include access panels at the nose and rear fuselage. These modifications were made to aid in accessing the interior of the aircraft for component installations. Other modifications include internal mountings for the security of the two required payload components. Cutouts were made to accommodate the air-drop subsystem and gimbaled camera. Finally, the aircraft structure was reinforced in the landing gear to reduce or eliminate stress and fatigue from the rigors of flight testing.

1.2.2 Autopilot Subsystem

The autopilot subsystem primarily consists of an Ardupilot Mega 2.6 (APM 2.6) autopilot which uses Arduplane software. This was chosen due to familiarity with the hardware and software, as well as the multi-function capabilities of the hardware and open source nature of the software. In addition, 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 uses a dedicated laptop computer running the Mission Planner software for writing waypoints to the airplane. For safety purposes, a 2.4 GHz radio is used to allow the safety pilot to take over the aircraft at any time.

1.2.3 Payload Subsystem

The mission payload consists of two subsystems: imagery and air-drop. The imagery subsystem is composed of a gimbaled camera and a 5.8 GHz transmitter and antenna to stream image data to a dedicated image processing computer. The air-drop subsystem is composed of a custom egg drop mechanism, which interfaced with the APM 2.6.

1.3 Expected Performance

This airframe and autopilot systems are a continuation of the system used in previous years. This was done because of their proven reliability and successful performance during the competition in the previous years. The platform is expected to meet and exceeds the majority of the threshold requirements of the previously mentioned tasks during competition. This is based on ten flight tests from the previous year and a further eight flight tests conducted in preparation of this year's competition. In addition, many hardware-in the-loop simulations have been performed to validate the flight control software, autonomous takeoff and landing, and obstacle avoidance.

The imaging system has undergone extensive testing and is expected to successfully meet required performance goals. The image downlink and manual target recognition systems are currently undergoing testing, but expected to meet requirements by 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. The software for autonomous rerouting for moving targets is still being tested, but is expected to be functional by the time of 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**
R7.4	Actionable Intelligence	**Requirement Met**	**Testing**
R7.5	Off-Axis Target	**Requirement Met**	**Testing**
R7.6	Emergent Target	**Requirement Met**	**Testing**
R7.9	Air-Drop	**Requirement Met**	**Testing**
R7.9	Interoperability	**Requirement Met**	**Requirement Met**
R7.11	SDA	**Requirement Met**	**Testing**

1.4 Programmatic Risks

One of the programmatic risks was the difficulty in scheduling a meeting time to work on the project. Because all members of the team were also full time undergraduate students, it was difficult to work around everyone's schedule. This was mitigated by instituting one general meeting time that worked for most of the members. Furthermore, the team was divided into sub teams in order to allow more flexibility in scheduling the meeting times. Related to this was the risk of not completing the task by the deadlines. This was mitigated by requesting sub teams to complete their tasks as soon as possible, more time and personnel were devoted as the deadline approached. This allowed tasks to be prioritized chronologically and be completed on time.

Another major programmatic risk that affected the project this year was the risk of being unable to flight test due to FAA restrictions on UAS testing, which includes student projects. These restrictions required students UAS teams to obtain a Certificate of Authorization (COA). This process takes a minimum of nine months to complete, which precluded flight tests for an entire academic calendar year. This was mitigated by obtaining permission to flight test in a restricted area.

2.0 UAS Design

2.1 Aircraft Design

2.1.1 Airframe

This year, it was decided to continue using the Sig Kadet Senior that was used in the previous years. This design choice was made because of its well-known characteristics. The Sig Kadet Senior is also a very stable platform. This helped in quick tuning of the controller gains for autonomous flight as well as for automatic takeoff and landing. Having a well-known system that required little work for gain tuning allowed for focus on developing software for detecting targets and their characteristics. It also allowed for the developing software for the SDA secondary task.

Figure 2.1.1: Sig Kadet Senior UAS

2.1.2 Power System

The design of the power system for UAS focused on reducing the weight of the power system and increasing the endurance. The power system also includes redundancy in case the primary power system failed during the flight. The power is supplied by three different lithium polymer battery systems. The first system, which is used to power the motor, consists of two 22.2 volt 6 cell 5000mAh batteries in parallel. The batteries are then connected to an electronic speed control unit, which regulates the speed of the motor. To reduce risk of losing propulsion power during flight, a voltmeter and ammeter are used to monitor the propulsion batteries. The signal from the voltmeter and ammeter are sent through telemetry to the GCS. The power for the motor was chosen for the maximum flight. This choice has consistently provided a flight time of between 15 and 20 minutes. This allowed the Sig to land to replace the batteries only one time during the mission.

The second power system is a 7.4 volt 1330mAh battery regulated to 5 volts, and is used for powering the autopilot, the servos for the control surfaces, and the receiver for the 2.4 GHz manual control radio. This power system has been chosen to last for about an hour, which is sufficient for the entire mission time.

The third power system is for the camera payload system. This system uses an 11.1 volt 3200mAh battery that supplies power to both the camera payload and the video transmitter for about one hour.

2.2 Autopilot

The autopilot being used this year is the Ardupilot Mega 2.6 (APM 2.6). This autopilot is also the same autopilot used for last year's competition. The reason that it was decided to keep the same autopilot was because it is an open-source autopilot. It was also determined that using this autopilot would reduce the development time by eliminating the need to learn a completely different system. An LV-MaxSonar®-EZ0™ ultrasonic sensor from MaxBotix was integrated into the UAS to add the capability of more precise altitude reading for takeoff and landing. With the combination of the Pitot-Static tube and sonar, the system is more capable of achieving a full autonomous mission. With the limited amount of flight time, most of the functions of the autopilot were verified with hardware-in-the-loop simulation.

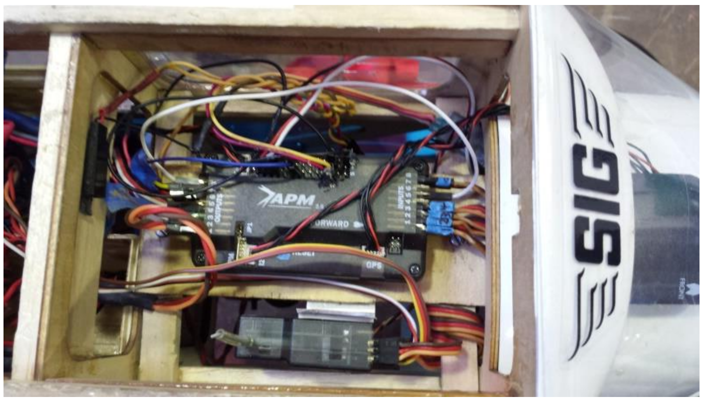

Figure 2.2: APM Autopilot

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

After last year's issues with maintaining connection to the camera payload and telemetry, it was necessary to change the antennas for the ground station to be directional instead of omnidirectional. The antenna selection for the UAS was narrowed down to what is shown in table 2.3.2-1.

Table 2.3.2-1: Antenna Selection

Purpose	Type of Antenna	Polarity	Gain (dB)	Beam Width (Degrees)	Weight (kg)	Price ($)
5.8 GHz Ground	parabolic	linear	24	12	1.4	64
	helical	circular	12.5	30	0.15	50
5.8 GHz Airplane	whip	linear	5.5	180	0.05	11
	clover	circular	1.4	360	0.05	50
915 MHz Ground	parabolic	linear	15	18	2.29	94
	Patch	circular	8	65	0.45	52
915 MHz Airplane	whip	linear	3	180	0.05	12
	clover	circular	1.4	360	0.05	34

The drawback to a linearly polarized antenna is that it does not maintain a strong data link if the two antennas are not properly aligned. When the antenna is rotated, linearly polarized antennas undergo changes in both amplitude and phase angle, whereas circularly polarized antennas only has changes in its phase [1]. Due to the airplane constantly pitching and rolling, the linear antennas can potentially lose data. The linear antennas generally have higher gain and range compared to the circular antennas. This is due to the difficulties in manufacturing circularly polarized antennas. A major influence on the selection was based on the fact that both antennas have to have matching polarity to have the strongest connection. The trade study used to determine what antennas were selected is shown in table 2.3.2-2.

Table 2.3.2-2: Antennas Trade Study

Purpose	Type of Antenna	Polarity	Gain(dB)	Beam Width	Weight	Price	Overall
5.8 GHz Ground	parabolic	0	10	10	1	7	28
	helical	10	5	5	10	10	40
5.8 GHz Airplane	whip	0	10	5	10	10	35
	clover	10	3	10	10	2	35
915 MHz Ground	parabolic	0	10	10	2	6	28
	Patch	10	5	3	10	10	38
915 MHz Airplane	whip	0	10	5	10	10	35
	clover	10	5	10	10	5	40

As a result of the trade study, the circularly polarized antennas were 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

The 3DR that was used for the last year's competition was selected due ease in connecting it to Mission Planner. To create a strong connection between the airplane and the ground station, the Ubiquiti Bullet M5 wireless radio was used. Last year, a lower powered router was used to transmit video to the ground station. The M5 radios were chosen because they can support a range performance up to 50 kilometer with up to 100 megabits per second (Mbps). This allows for a decent quality imaging to be transmitted from the ends of the flight zone to the ground station.

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. The reason for only three payloads was because this would allow the UAS to accomplish the maximum number of tasks with the minimum amount of weight.

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 used to attempt to automatically detect targets by processing the video onboard. Unfortunately, this was not tested enough and no targets were detected. This year it was decided to send the images directly to the ground station for manual target detection. This is a trade off since the M5 bullet has a bandwidth of 100

Mbps and the camera transmits approximately 300 kilobytes per frame. As a result of this trade off, the quality of the image is reduced to 480 p at 10 frames per second (fps). After testing, the quality achieved allowed easy identification of targets with a minimum dimension of two feet.

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 payload drop was designed for the purpose of the egg drop task. The drop mechanism consists of a casing for the plastic egg and a spool for the ribbon. The spool was a new addition this year to prevent the possibility of the ribbon getting caught on the servo release mechanism. A servo holds the payload securely until the safety precautions of the system have been met and when it has reached its desired GPS coordinates. The drop process is autonomous once the safety pilot arms the system. The payload drop location is calculated so that the payload arrives at the desired location precisely.

2.5 Ground Control Station

The Ground Control Station (GCS) consists of an antenna tracking system and four laptop computers. The four computers will be utilizing the generator provided, and will consist of two stations. The first station uses the Mission Planner software and the other station uses the image processing software which will be further explained. Uniden hand held radios are used to ensure proper communication between the GCS crew and the safety pilot minimizes error and potential risks.

2.5.1 Primary Mission Planner computer

The objective of this computer is to use the Mission Planner 1.3 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 **Primary Imaging Computer**

The main objective of this computer is to receive images from the camera as well as telemetry data from the primary Mission Planner computer. Proprietary software based on the libraries of FlyCapture2 and OpenCV is used to process the images received from the camera. This station displays the images as a video and the user finds and identifies targets. This software will be further described in section 2.6.1. When the first target is found by the user, its info is transmitted to the secondary computer. It is important for this operator to communicate with the other stations. This is because this station will inform the primary and secondary Mission Planner computers if the general search area or emergent target needs to be searched a second time. The other objective of this computer is to take the telemetry data from the Mission Planner computer and add it to a tab delaminate text file as per the competition requirements.

2.5.4 **Secondary Imaging Computer**

The main objective for the secondary imaging computer is to process the transmitted data from the primary imaging computer for actionable intelligence. The secondary imaging computer was included because the actionable intelligence task requires the operator to focus on one target instead of the overall search area. Communication with primary imaging operator is important for the secondary imaging operator to ensure that the actionable intelligence task is performed efficiently.

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. It was decided to build the tracker instead of purchasing an off-the-shelf tracker primarily due to the cost and customizability. The custom tracker includes a slip ring, continuous rotation servo, metal geared servo for the tilt motion, magnetometer, and Arduino Uno board. 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. The tracker is controlled using the Mission Planner software, which already included a piece of code for the tracker. Modifications were needed to be made to the software for interfacing the tracker with the Arduino Uno and the continuous rotation servo. The Arduino Uno was needed to make a connection between the HMC 5883L magnetometer and the Mission Planner for the pan.

2.6 Data Processing Design

2.6.1 Image Processing

Software was written to assist with the search area, actionable intelligence, off-axis target, and emergent target tasks. All four tasks are handled by the same software, which is broken down into four sections: manual target detection, video review, target evaluation, and target classification.

2.6.1.1 Manual Target Detection

For Manual target detection, the program retrieves the image from the FLEA3 camera. Then, in real-time, the software converts it to an image format, which is compatible with the OpenCV library. It saves the image into a pre-set location and displays the image to the user. During this mode, if a target is seen, the user provides input, which allows the program to save the picture manually with the location of the target. The information about each image is saved into a text file within the same folder as the images. The image stream continues until the end of the flight or until the user decides to end the stream.

2.6.1.2 Video Review

During the video review, a target can be saved, similar to the manual target detection and identification process. However, this option includes rewind, pause, and video playback speeds. This is a redundant system, which allows the user to watch the video during the data processing portion of the mission if there were any issues with finding targets during the flight.

2.6.1.3 Target Evaluation

Each image that was saved as a target in manual target detection or the video review phase is displayed for further review. This allows users to navigate between images before and after the marked picture to determine the best target picture. If any false positives were noticed, the user can make a request to remove it from the list of the targets.

2.6.1-4 Target Classification

Target classification starts by matching the targets to their corresponding GPS data. The target is then displayed and the information about the target is provided by the user. The information provided by the user and data from the telemetry processing is put into a tab delimited text file as per the requirements outlined in appendix D: Electronic Target Data Format of the Competition Rules.

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 five tasks: the primary objective, actionable intelligence, emergent target, 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 two parts. The first half 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 other half 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 7.10 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.

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, stationary obstacles, and Moving obstacles. The software then determines what moving obstacle is in closest proximity to the airplane. Then, the software calculates if the moving obstacle and the airplane will intersect. If they do intersect, the software creates a new waypoint path for the airplane, which will allow it to avoid the moving obstacle. The software then checks if the new waypoint path 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.

2.7 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.

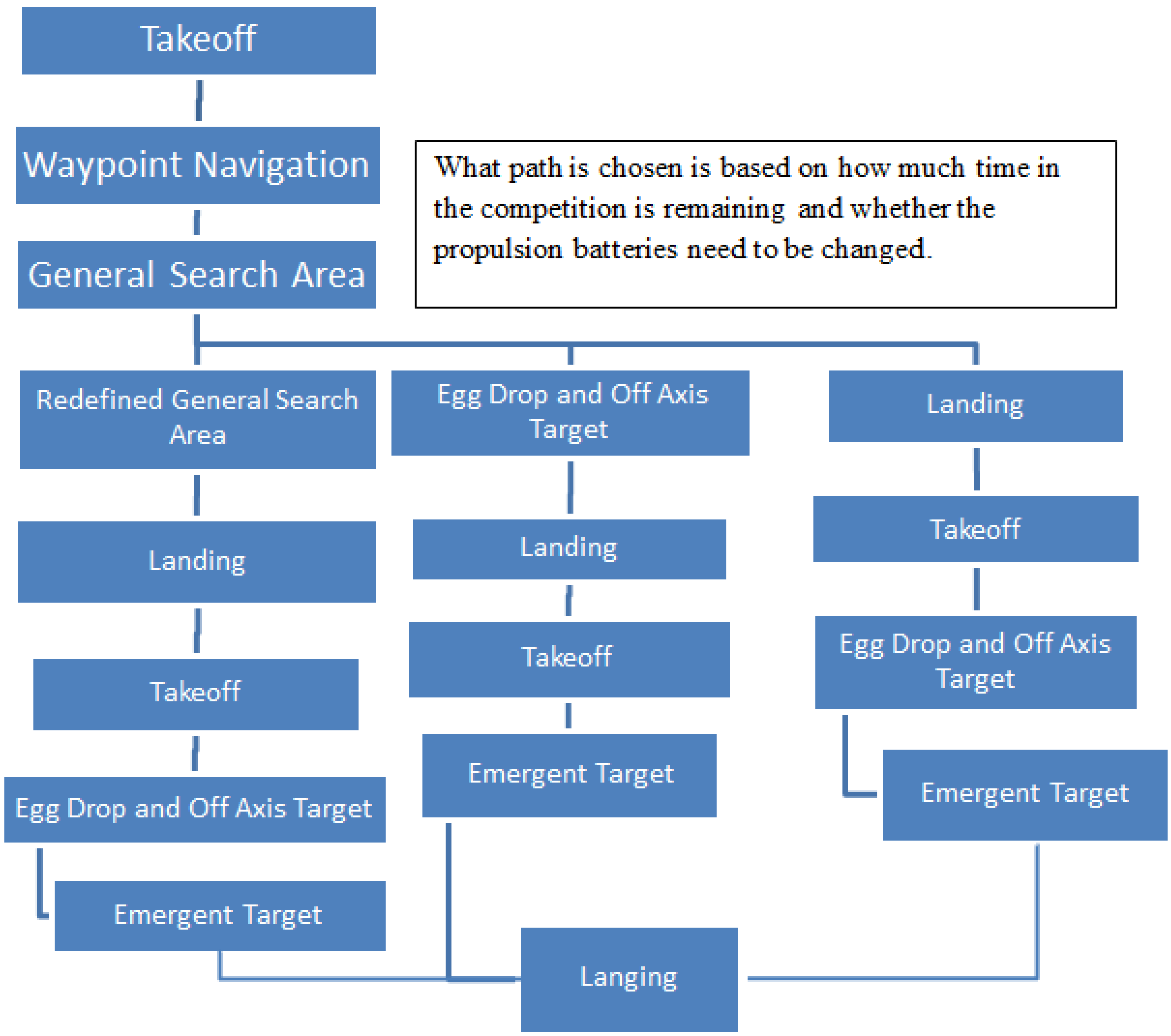

Figure 2.7-1: A Flowchart of the Logic that will be used during the Mission

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 and the airplane. This 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.

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. Otherwise, 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 egg drop. After the airplane descends to 150 feet above the MSL, the UAS will perform the off-axis target task.

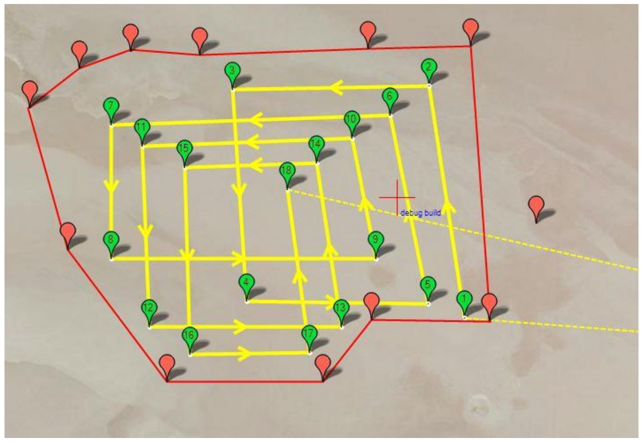

Figure 2.7-2: Example of Overlapping Grid

After the egg drop and off-axis target path is completed, the first landing path will be loaded. This will allow for the propulsion batteries to be replaced with two fully charged batteries. The landing mission has two different path scenarios due to different wind conditions. It is important to note that this phase in the mission can occur before the egg drop mission if the general search section is to be searched again for better results. Once the airplane has landed and the batteries have been changed, the airplane will run the takeoff path again and once in the air, the emergent target path will be loaded to the airplane. Due to the emergent target location being 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 7.10.9 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.

The moving SDA software is still being developed and will be tested in hardware-in-the-loop simulation. The software for moving obstacles is expected to meet the objective in time for this year's competition.

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 egg and ribbon successfully cleared the launch tube without being caught on the servo release mechanism.

3.3 Autopilot System performance

3.3.1 Hardware-in-the-Loop Simulation

Mission Planner's Simulation software was used to preform hardware-in-the-loop (HIL) simulations. First, the ground station was connected to the APM by a USB cable, and the safety pilot's radio was activated. After loading the X-Plane 10 flight simulator with a virtual model of the airplane, the hardware-in-the-loop test was started in the Mission Planner. This allowed the autopilot to control the airplane as if it was in actual flight. Flight characteristics were validated by observing the performance of the model in the X-Plane simulation.

Figure 3.3.1-1: Simulation of the Airplane Motion in the X-Plane Flight Simulator

During the HIL testing, the autopilot successfully navigated a diverse waypoint patterns. In addition, the autopilot was successfully re-tasked with new missions in flight, demonstrating the responsiveness of the system. Nearly all competition missions planned to be attempted were successfully modeled and flown in the HIL simulation. This includes the waypoint navigation, search area, off-axis target, air drop, and emergent target tasks. These tasks were simulated by having a moderator providing information about the wind conditions, waypoint navigation, search area, payload drop location, and off-axis target location prior to the simulated mission. The moderator then provided the information about the search area of the emergent target upon mission start and provided the last known waypoint upon takeoff. The secondary Mission Planner Operator was capable of creating a new search pattern well ahead of the time the waypoint file was needed. Only the SDA task has not been modeled due to the necessary code still being developed.

The HIL simulation was also used to perform potentially hazardous testing without putting the actual aircraft at risk. This includes automatic takeoff and landing. Both of these were successfully tested in simulation, with few complications, but more simulated testing and actual flight testing will be performed before the decision to attempt these tasks during the Competition.

3.3.2 Flight Testing

This UAS has completed ten flight tests in the previous academic year and eight further flight tests this year, for a total of eighteen flight tests over all. These tests were performed at Prado Airpark in Chino, California. These flight tests were student led and student conducted, following detailed flight cards and pre-flight checklists. About two flight tests were performed during each trip, with a break between each test to change flight batteries and modify autopilot parameters. The 8 flight tests this year were completed without the occurrence of any significant mishaps. Waypoint navigation was successfully accomplished during flight testing.

Flight testing this year was limited due to the regulations imposed on the team by FAA. These regulations required all students operating UAS to obtain a Certificate of Authorization (COA) from the FAA before flight testing. However, Cal Poly Pomona has recently obtained access to a restricted airspace for flying its UASs. This will allow the team to conduct flight tests at the airspace soon.

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. First, the hardware-in-the-loop testing of the autopilot system has shown that the UAS can successfully accomplish autonomous waypoint navigation, search area, off-axis target, payload drop and emergent target tasks. Secondly, 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. Tasks such as payload drop, autonomous takeoff and landing, and SDA tasks are expected to be functional at this year’s competition, but with less confidence.

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, Pitot-static tube, and sonar
- 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 electric motor, 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. The propulsion system in particular is powered by two batteries in parallel, so that even if one fails, the engine will retain enough power to safely land. 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

The major risks and their mitigations methods are listed below:

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, the motor power will be cut, and 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 Sig Kadet Senior airframe, a 3D Robotics APM 2.6 with Arduplane 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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