AUVSI SUAS 2018

Project Jatayu, RV College of Engineering

ABSTRACT

In preparation for AUVSI SUAS 2018, Project Jatayu's objective was to design, develop, fabricate and verify an improved system that surpassed the system demonstrated at last year's competition in all aspects. Undergraduate students from the Aerospace, Electrical, Electronics, Mechanical and Computer Science Engineering departments worked together to develop a newer and more efficient system that met all competition requirements. The airframe was subsequently integrated with an open source flight controller to give the plane autonomous capabilities. Efficient data link systems and image processing algorithms were developed to allow the UAS to achieve the secondary tasks smoothly and accurately.

Contents

1. Systems Engineering Approach

For the SUAS 2018 competition, the team is aiming to complete the following tasks; Automatic Detection, Localization and Classification (ADLC), Airdrop, Actionable Intelligence, Static SDA, Waypoint Navigation, Search Area, Emergent Tasks and Interoperability. The team is focussing on a systematic and prioritised approach in order to accomplish the set goals.

1.1 Mission Requirement Analysis

The mission tasks were assessed and prioritized by the team on the basis of the following parameters:

- **Importance**: The relative weightage of every task was noted and the team accordingly prioritized the tasks to be attempted so as to maximize the points.
- **Ease of Implementation**: Each task was assigned a grade to determine how easy it would be to implement in the current system.
- **Budget**: Each task was assigned a grade to show if it would be feasible under the restrictions of our current budget.

1.2 Design Rationale

The spiral model is a popular design model. It emphasizes risk management to find major problems earlier in the development cycle. In contrast to the waterfall model, where the design is completed before coding is started, the project is broken up into a set of risks that need to be dealt with. A series of iterations is started in which important risks are analyzed, options are evaluated to resolve and deal with each risk, assess the results, and plan the next iteration. The following illustration shows the spiral life cycle model.

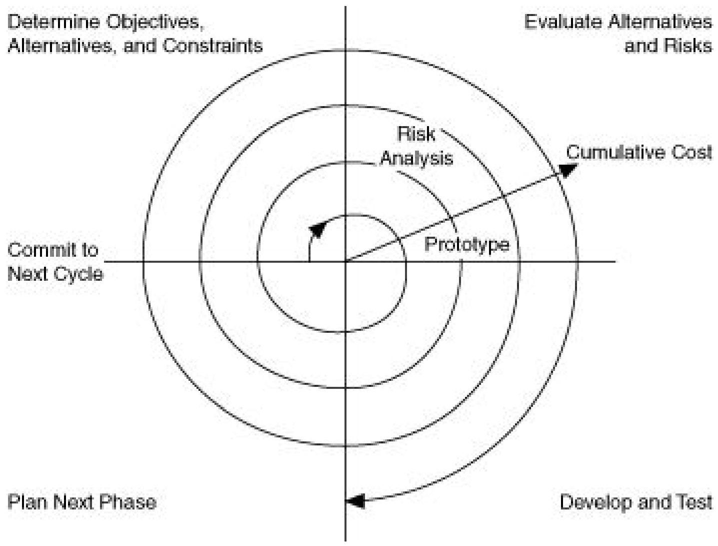

Figure 1: Spiral Model for iterative development

In the iterative model, a high-level design of the application is initially created and the design solution for the entire product is defined. At the next stage, a skeleton version of the product is developed, keeping in mind the high-level developed initially. The design is then continuously evolved and updated based on the feedback received on what has been built. The system is therefore incrementally built and improved step by step. This helps track defects at the early stages and prevents the propagation of errors and defects into later stages in the development cycle. This model is exemplified by the team's system.

The team's image processing system was initially implemented using a foreground extraction method and written in C++ which was used in the previous competition. This approach was later changed, as the use of Python and certain other algorithms yielded better results and satisfactorily met the team's expectation to meet performance requirements.
Similarly to choose the relevant frame various approaches were tried and tested. Quadcopter, hexacopter and an octocopter were tested on numerous parameters such as stability, ease of control and handling. The budget constraints were also taken into account to narrow down to a reliable and agreeable solution. As a result a hexacopter was selected which met all the mentioned criteria after rigorous testing of different models.

1.3 Expected Task Performance

In SUAS 2018, we expect to see an improvement in the flight systems this year. Many major modifications have been made to our system and new hardware promises achievement of the mission parameters. The Team is planning on a one stop strategy to change battery as the maximum flight time noted is around 20 minutes during testing. The primary task of autonomous navigation will be completed, followed by the ADLC task. The ADLC system has been designed and tested to meet the thresholds and achieve better performance than the set thresholds. A 14 MBps connection up to a range of 2 km is seen during testing.
The interoperability task will be successfully completed above the required threshold. The team is confident of the new air drop mechanism which will allow a bottle to be dropped onto the bull's eye. As an addition to last year's attempts, the static SDA task will be tried this year but the off axis task will not be attempted.

2. System Design

2.1 Airframe Design

During the airframe selection process for this year's competition, we performed a relative performance assessment on the basis of the important flight parameters required for the competition. We took into consideration three available types of airframes namely; multi-rotors,helicopter and a conventional fixed wing. The evaluation was based on detailed calculations as well as past competition experiences. Hence we arrived at the conclusion of choosing a hexa-rotor for the SUAS 2018 edition.

SI/No	Parameters	Multi-rotors	Helicopter	Fixed Wing
1	**Navigating in tight spaces and performing quick maneuvers**	High	High	Low
2	**Controllability**	High	Low	Medium
3	**Payload Capacity**	High	High	Medium
4	**Maximum Flight Speed**	Medium	Medium	High
5	**Endurance**	Medium	Medium	High
6	**Ease of Fabrication**	High	Low	Low
7	**Stabilization**	High	High	High
8	**Performing autonomous flight**	High	Medium	Low

9	**Affordability**	High	Medium	Low
10	**Testability**	High	Medium	Low
11	**Crash Proof**	High	High	Low

Table 1: Airframe design details

Parameters	Quad-rotor	Hexa-rotor	Octa-rotor
Thrust achieved	Low	Medium	High
Weight efficiency	High	Medium	Low
Stability	Medium	High	High
Affordability	High	Medium	Low
Payload Capacity	Low	High	High
Safety	Low	High	High
Endurance	High	Medium	Low

Table 2: Performance of multi rotors

Taking into account the relative advantages of the hexacopter, we have selected it as our airframe due to its robust properties and maintaining a good endurance while having a good payload capacity. It makes it possible to take really highly stabilized images while hovering in air. Due to the requirement of high resolution images for targets extraction, hexacopter frame has good vibration mitigation.

We have chosen a off the shelf ZD-850 hexacopter frame due to its high payload capacity and trusted performance .The frame is made entirely of carbon fiber composite material having an arm diameter of 850 mm. The tubes are hollow in nature helping in massive weight reduction of the entire frame. It provides a good ground clearance for housing of multiple levels of payload for housing the image processing equipment, Odroid U3, Pixhawk autopilot,GPS with magnetometer,power distribution circuit as well an extended surface for attaching the gimbal. The 3 axis Gimbal provides an unrestricted, clearer view of the ground surface suitable for performing the image processing tasks.

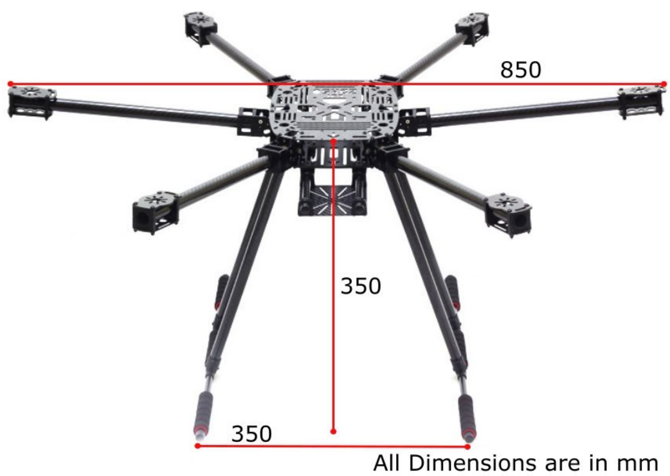

Figure 2: Dimensions of the Hexacopter

The payload of the UAS consists of

1. Odroid U3 (on board processor)
2. Drop Box (will contain the air delivery apparatus)
3. Lithium Polymer Batteries
4. Rocket M5
5. PixHawk (Autopilot)
6. Sony DS-QX100 Camera
7. 3 Axis camera Gimbal
8. Buck DC-DC Convertor

2.1.1 Propulsion Systems

We deduced that an electric propulsion system would be more suitable than the gasoline system due to the absence of undamped vibrations and combustion related exhausts which affect the functionality of the vehicle and the incorporated systems.The propulsion system has several fundamental requirements: provide enough power to complete the mission's tasks, maximize the cruise speed for area survey all while maintaining a low system weight. The selections of motors were highly important as to the overall performance of the hexacopter. By a detailed calculation setup, the assembly composed of the motor-propeller was computed for a flight time of around 30 minutes during testing phase with one stop for replacement of batteries.

Model	Voltage (V)	Propeller	Current (A)	Power (W)	Thrust (G)	Efficiency (G/W)	Weight (6xMT3515)
EMAX MT3515 650kV	22.2	1238 Carbon fiber	10	222	1300	5.9	786g
			18	399.6	1920	4.8	
			27.3	606.6	2550	4.2	

2.1.2 Gimbal

The necessity of the gimbal is to dampen vibrations for clear images, therefore a 3-Axis Brushless Gimbal is selected for rough damping. The Gimbal is controlled using a Storm-32 controller.

2.2 Autopilot

The UAS required an autopilot that was reliable and tested. Using a familiar system meant saving time that would otherwise be used on experimentation. It was also desirable to use an open source autopilot in order to have large community support. As a result of these considerations, Project Jatayu has opted to use the autopilot mechanism that is a part of the documentation of the Ardupilot Copter website documentation.

Project Jatayu needed to ensure quick replaceability of the autopilot module in instances of malfunction or damage during test flights. This meant that the autopilot would have to be both low cost and easily acquirable. Realizing that processing capabilities would be pushed to the limits during execution of tasks as demanding those of SUAS, less reliable and powerful options like the APM 2.6 were dismissed. Having arrived at the above considerations, Project Jatayu decided to use the 3DR Pixhawk.

The Pixhawk comes equipped with a gyroscope, accelerometer, magnetometer, and GPS. It will be outfitted with an airspeed sensor so that the autopilot can maintain the speeds required to maintain altitude. It also has channels available to output servo signals for camera stabilization, which are utilized by the payload stabilization system. The autopilot interfaces with the ground station using the program Mission Planner. It displays telemetry and location in real-time and allows the user to set waypoints and flight commands. The interface allows the user to specify instructions such as automatic takeoff, landing, as well as the creation of complex search patterns.

2.2.1 Mission Planning

Mission planning will be done one day prior to the competition by the autopilot operator in consultation with the safety pilot (to determine if the chosen flight path is within the aircrafts permissible operation conditions). On the day of mission demonstration, mission start will be initiated only on the approval of four key members. Namely judges will inform of mission time start. The safety pilot shall do the pre-flight checks to determine of the aircraft is safe to get airborne. The GCS operator (autopilot operator) shall give consent to start mission indicating all parameters of the autopilot are setup correctly. The interop operator shall give approval of flight once connection is established with the inter-op server successfully. Figure 18 shows the control authority and mission plan.

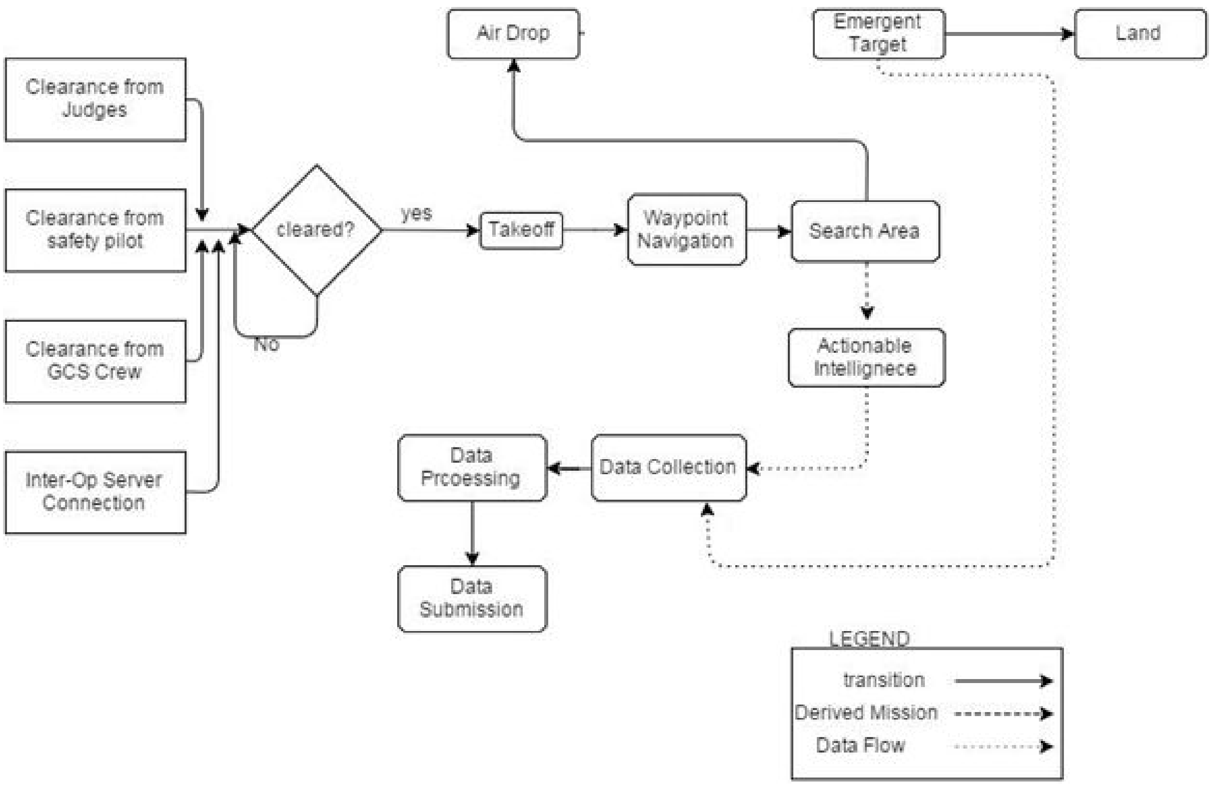

Figure 3: Mission Planning Flow Chart

2.3 Imaging System

The camera must be able to photograph small targets (roughly 5 to 10 sq. ft.) in a large field. The camera used by the team this year a Sony Cyber-shot DSC-QX100. A comparison between the camera used this year ad the camera used in the previous competition is shown below:

	Sony DSC-QX100	Canon Powershot-S100
Image resolution	5472 x 3648 (20MP)	4000 x 3000 (12MP)

Video resolution	1440 x 1080 (30p)	1920 x 1080 (24p)
Focal Length	10.4-37.1 mm	5.2-26 mm
Approx. Pixel Pitch	2.41 microns	1.9 microns
Weight	179 g	192 g
Size	2.5 x 2.2 x 2.2 in.	3.9 x 2.4 x 1.1 in.
Sensor size	13.20 x 8.80 mm	7.6 x 5.7 mm

Table 3: Comparison of Specs of the two cameras

The camera was chosen for its high resolution of 20 MP and its large sensor, which allows more light to reach each pixel than smaller, lighter cameras and captures sharper, noise-free images. Furthermore, the camera offers control over options such as optical zoom and angle of the aperture, shutter speed, exposure and ISO.

2.4 ODLC(Object Detection, Classification, Localization)

The team's approach to Automatic Target Detection, Localization and Target Classification is a robust image processing and target identification system. The image processing system is written in Python3 and OpenCV version 3. OpenCV was designed for computational efficiency with a strong focus on real-time image processing. OpenCV application can easily be integrated to other applications and devices. The system can work either on a MacOS platform or in a Linux environment. MacOS Sierra and Ubuntu 16.10 along with Ubuntu 17.10 were used to develop and implement the algorithm.

2.4.1 Pre-Processing

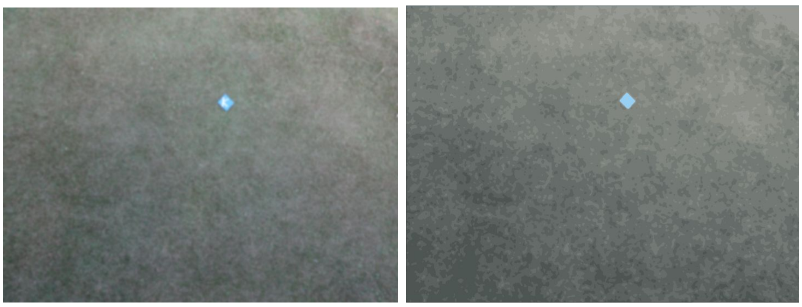

Figure 4: Image obtained after preprocessing

Preprocessing the input image reduces the noise and enhances the edges for object detection and target localization. A simple Gaussian Blur with a kernel size of 9X9 is used to achieve this. This forms the first step of pre-processing. The second step involves smoothening the background and differentiating it from the target. The k-means algorithm is used for this purpose and to improve the pre-processing.

2.4.2 Target Detection

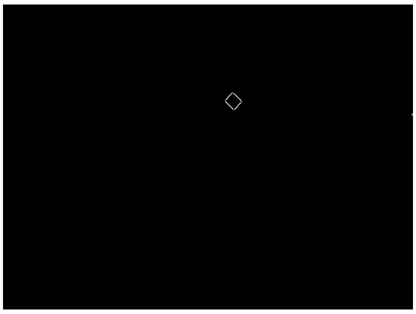

Figure 5: Target detection after background removal

After preprocessing the image the target is extracted using a simple but effective algorithm that checks for various contours that are detected after the removal of background noise. The *Canny Edge Detector* is used to check for edges in the processed image. Contours are detected using OpenCV's Contour Detection Algorithm. The area of each detected contour is calculated and the irrelevant contours are rejected. A list of probable contours is generated.

2.4.3 Target Extraction

Figure 6: Extracted target

For target localization, the algorithm retrieves the list developed in Step 2, and identifies the contour with the largest area. This contour is then extracted from the background.

2.4.4 Shape Detection

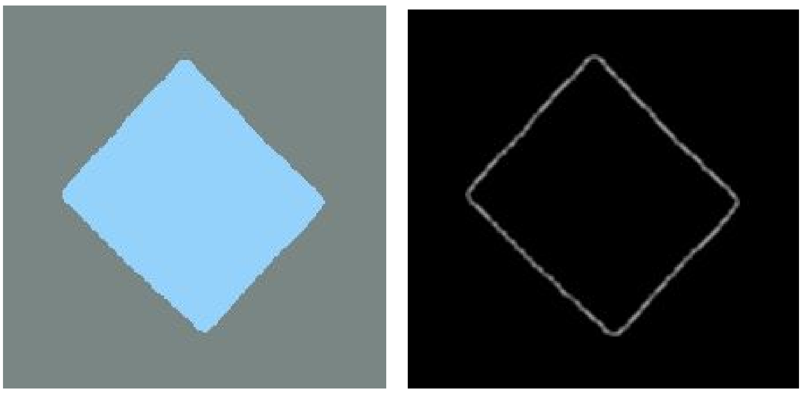

Figure 7:Shape detection of the target

Recognizing the shape of the target obtained from the previous step is carried out using the k-means algorithm. The image is divided into 2 clusters based on color. One cluster represents the background while the second one represents the object. Canny Edge detection is used to enhance the edges and Contour detection is applied to detect and outline the shape. The algorithm then identifies the contour and detects the shape on the basis of geometrical calculations.

2.4.5 Character Extraction

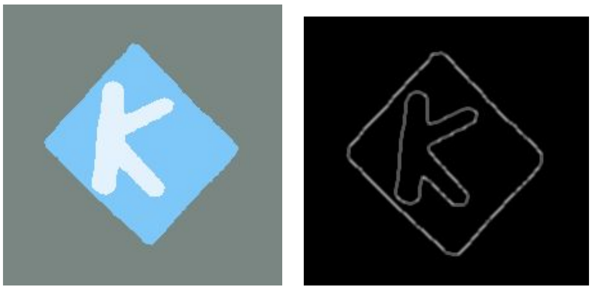

Figure 8: Alphanumeric character extracted from target

The next task deals with the extraction of the alphanumeric character from the target. Again, a K-means algorithm is used (on the image obtained from step 3) to divide it into 3 separate color clusters. From the processed image contours are detected and the contour with the least area is separated. The image is thresholded and only the area lying between the contours is extracted after thresholding. The image thus obtained is written into a file for further processing and character recognition.

2.4.6 Character Recognition

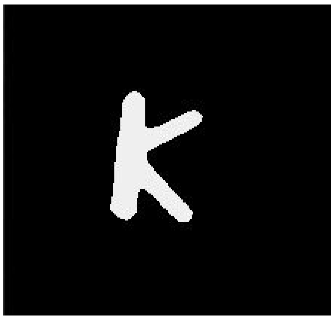

Figure 9: Binary image fed to the OCR engine

The image obtained from Step 5 is binary (i.e. it has only 2 pixel values, black and white). It is fed as an input to Tesseract, an OCR engine. Tesseract rotates the image and compares it against all 26 characters, obtaining a *confidence level* for each of them in the process. The character with the highest confidence level is returned as the recognized alphanumeric. For ease of use, and to improve the accuracy, the system is trained to identify only alphanumeric characters. Special characters are ignored.

2.4.7 Color Detection

Colour values are scattered due non-uniform illumination, and camera optics. Hence clustering them is the best approach before finding the colour of target and alphanumeric. After clustering the largest cluster indicates the object. The second largest cluster indicates the alphanumeric colour. Based on the LAB properties Euclidean distance is calculated to certain predefined centers and the color name associated to the nearest center is considered as the color name. LAB color space remains the most relevant color space to apply Euclidean distances and shows less variance in varied illumination levels, hence this color space was chosen.

2.4.8 Target Localization

To successfully complete the ADLC task, the UAV needs to be able to acquire GPS and compass data for the image being taken. This must be done without adding much weight or cost to the UAV/Project. To implement this, a custom Python algorithm was developed. The algorithm intercepts and reads the stream of MAVLINK messages being sent to the GCS. Message acquisition is done through a serial to USB device connected to the ODROID and the TX pin of the secondary serial port on the PixHawk. The code scans all the messages being sent and saves the message with the required set of data into the buffer. The GPS data (latitude and longitude) and compass data (orientation in degrees is extracted) are then collected. This data is then injected into the respective image and subsequently transferred to the ground station where further processing is done.

2.5 Communication

Communication with the ground station was established over two independent RF links: Two 915 MHz telemetry modems were used to relay navigation data between the pixhawk and the ground station. The telemetry link uses the Mavlink Protocol to pack C-structs over serial channels with high efficiency and send these packets to and from the ground station. A 5.8GHz data link channel was used to control the camera and monitor the imagery systems and transfer the images captured to the ground system. The RF signals were relayed to and from the ground station using a Ubiquiti Bullet M5 modem mounted on board the UAV. The data link operates as a Line of Sight communication channel over a range of 5Km.

Primary communication with the UAV is done via a pair of Rocket M5's. On the ground station is a Rocket M5 connected to a pair of 12dBi helical antenna, which the team has fabricated keeping in mind the distance to be covered. The antennae have a beam width of approximately 40 degrees which is wide enough to keep the UAV inside communication sight at distances of a few KMs. The reason helical antennas were chosen is because when paired with a compatible circular polarized antenna, it provides great multipath rejection capabilities thus improving the bandwidth efficiency and throughput. On the UAV, a de-shelled Rocket M5 rests connected to a pair of cloverleaf antennas fabricated by the team (basically a 3 lobed skew planar wheel antenna). The current system is able to provide us with data link speeds of up to 30Mbps with a distance of about 2 KM which is sufficient as per the competition distances. The Rocket M5's are locked to each other in the 5.8GHz band with a 40MHz bandwidth ideally capable of providing up to 200Mbps.

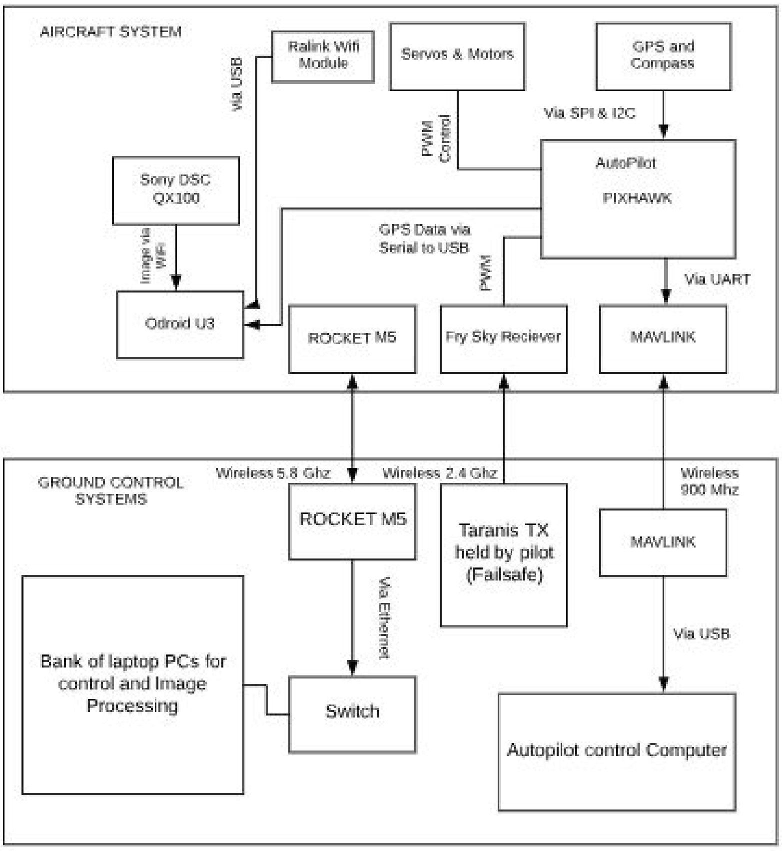

Figure 11: High level block diagram of the System

In summary, the odroid controls the camera to take pictures every 6s at the same time it takes in the GPS data from the pixhawk and sends them to the base station using Rocket M5. The base station then performs the odlc task on the received data and send the results to the judges server using the interoperability system. The base station also receives the mission details from the interoperability system and uses the MavLINK protocol to communicate with the pixhawk on the UAV. For safety measures a Fry Sky receiver is fixed on the UAV which can receive the signal from a transmitter for a failsafe option.

2.5 Air Delivery

The rectangular drop box is made up of balsa wood ply fitting a 8 oz water bottle of 180 mm length. The two segments of the lock door is controlled with the help of the servo mechanism. The servos hold up the weight of the bottle and upon servo initiation, the gravitational force forces the bottle down. During testing, initially there was a delay in the opening of the hatch but after a few trials, the bottle could be dropped at bulls eye.

2.6 Cyber Security

Cyber security is a very important factor nowadays especially in the case of UAVs. Unauthorized access to UAV networks could result in catastrophic disaster. To prevent this from happening, Project Jatayu has worked hard to keep all the UAV networks encrypted.

2.6.1 Primary Data Link

For the primary datalink, Project Jatayu uses a pair of Rocket M5s from Ubiquiti. The Rocket M5 has inbuilt support for WPA2-AES encryption which is the latest encryption standard for wireless networks. This prevents any unauthorized access to the network, thus preventing access to the traffic movement through the network. Further, we have also configured the rocket M5 to hide its SSID. This means only the devices have been paired to the Rocket M5 through the configuration page is capable of seeing the network and connecting to it.

2.6.2 Autopilot Data Link

The 3DR radios work over an unencrypted channel at 915MHz. The pixhawk outputs headerless c packets to the 3DR radios and they transmit it over the channel to another 3DR device which it is bound to. The binding is done via a device ID ranging from 0 to 256. Anyone with 3DR radios can scan through the air interface and search for the ID and be able to send unauthorized messages to the UAS which could be a command to crash the aircraft. This could lead to be catastrophic both for the team and the safety pilot. To go around this vulnerability, the networks team of Project Jatayu is developing a hardware level encryption device using basic digital gates and shift registers. Once this device has been developed, and tested to the full satisfaction of the safety pilot and autopilot operator; then the encryption system shall be implemented into the UAS system at the competition. Safety is a top priority, if the developed system doesn't work up to the satisfaction of the concerned people, the device shall not be used in the competition.

3. Safety, Risk and Mitigations

The UAS has been developed in accordance to the rules to 2018 rules for AUVSI Seafarer Chapter's 16th Annual Student UAS (SUAS) Competition. Dropping mechanism has a dual authority feature which results in safer payload dropping. Aircraft has been configured to continue if there is a loss of communication for less than or equal to 5 secs but if the signal is lost for a minute, aircraft returns back to launch and circles around home until communication has been established again. Competition aircraft has logged minimum hours of required flight duration and was safely tested for various tasks. Safety Pilot has also logged in minimum number of required flight hours on the competition aircraft. This is done to achieve a safe and successful flight

3.1 Development Risk and Mitigations

The team's approach to tackle development risk and mitigation was to use an iterative model to enhance safety measures at each stage of development. Development risks include risks posed by budget limitations, which can lead to depreciation in quality along with design issues.

Risk	**Description**	**Impact**	**Likelihood**	**Mitigation**
Crash while testing	A crash while testing may lead to damage of airframe beyond repair	HIGH	LOW	Successful Flights, safety pilot is experienced. Rigorous pre-flight checks done to ensure no failure
Safety and legal issues	The system should comply	HIGH	LOW	Keeping the rules in

	with all the safety rules of the competition			mind from preliminary design to final flight aircraft.
Funding and Finance	Inadequate financial support may lead to unwanted compromises in quality and reliability of the system	HIGH	LOW	Pre acquiring the funds and pre-order the materials required.

3.2 Mission RIsk and Mitigations

Risk	**Description**	**Impact**	**Likelihood**	**Mitigation**
Subsystem issues	Any technical snag in vital subsystems may impact their performance of the UAV	HIGH	MEDIUM	Supervising every step used in fabrication and reducing the manufacturing defects
Insufficient training	Lack of training of crew may lead to ineffective mission operations	MEDIUM	MEDIUM	Minimum Flight Testing has been achieved with all team members present.

3.3 Autopilot System Performance

Thorough ground testing were carried out, validating system reliability. This included system integration, sensors accuracy, algorithm examinations and inspection of changes compared to last year's system. Following successful ground testing, the system was installed on a simple RC model airplane and basic performance were tested. Once confidence was gained, the AP was fitted to the new airframe and extensively checked: waypoint navigation ability, altitude & speed tracking, survey performance and system maneuverability. Once final parameters were set, 75%.of flight time was performed autonomously, while the safety pilot takes control only in cases of an emergency.

3.4 Evaluation of Results

Primary Tasks table:

Primary Tasks	Threshold	Objective
Take-off	Will Meet	Will Meet
Flight	Will Meet	Will Meet
Waypoint	Will Meet	Will Meet
Landing	Will Meet	Will Meet
Target Localization	Will Meet	Will Meet
Target Classification	Will Meet	Will Meet

Secondary Tasks table:

Secondary Task	Threshold	Objective
ADLC	N/A	Will Meet
Actionable Intelligence	Will Meet	Will Meet
Off- Axis Target	Not Attempted	Not Attempted
Emergent Target	Will Meet	Will Meet
Inter-Op	Will Meet	Will Meet
Air Drop	Will Meet	Will Meet
SDA	Will Meet static only	Will Meet Static only