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PROJECT JATAYU

ECLIPSE

Abstract

This technical paper outlines the design of Eclipse, the UAS developed by Project Jatayu, for AUVSI SUAS 2019 competition. This system was designed, fabricated and tested rigorously by the students from departments of Electronics and Communications, Computer Science and Aerospace Engineering. The paper conveys the team's motivation behind decisions and improvements in the overall system. A breakdown of tasks, design and tests in each subsystem are described in detail. This paper is divided into three sections, Systems Approach, Design and Safety Risks and Mitigations. Project Jatayu's primary objective is to increase stability, durability and improvement in meeting the mission objectives. Extensive simulations were run and prototypes were tested with regard to overall performance.

1.Systems Engineering Approach

The UAS system, Eclipse, has been designed by the team using an Iterative and Incremental development model. The system is capable of autonomous flight, image surveillance, obstacle avoidance, autonomous and manual object detection. An iterative development model was selected due to its flexibility and emphasis on gradual improvement. This developmental methodology is also known as "evolutionary acquisition" or "incremental build" approach.

In continuation with last year's developmental approach, the team decided to use the spiral development. The Spiral model is one of the most widely used Software Development Life Cycle models. It emphasizes on risk identification and risk management, along with screening of major problems in earlier stages of development cycle. Mission tasks were assessed and prioritized by the team on the basis of importance, ease of implementation and budget.

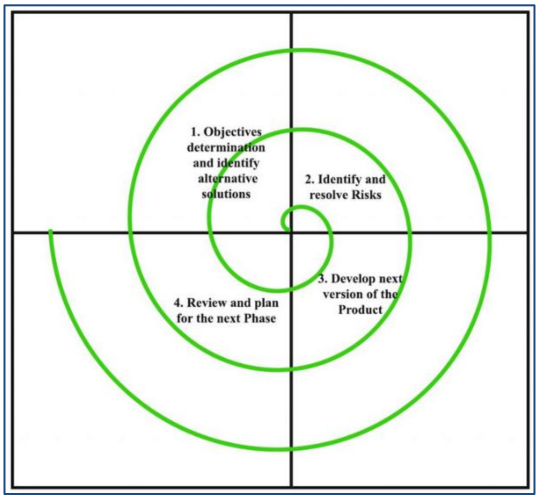

Figure 1. Spiral model for iteration

Project Jatayu used the last year's system as starting place for the development of the 2019 system. Improvements were made in the object detection and localization tasks, along with gimbal design. Selection of the new airframe was done to accommodate more electronic equipment and provide higher stability. Prototypes of the software are continuously developed and improved on the basis of their performance and reliability on the mission tasks. Spiral model allowed for the development and testing of the manual graphical user interface (GUI) and autonomous system, for the object detection and localization task, in parallel with each other.

1.1 Mission Requirement Analysis

Project Jatayu's objective is to develop an efficient and dynamic UAS to meet the objectives for mission completion and to adhere to safety regulations, which were met through several optimizations and enhancements. The UAS went under multiple rounds of augmentation so as to reach closer to an ideal version of a UAS with minimal points of failure. The table below describes the tasks and objectives of the mission, along with the trade-offs and the corresponding system requirements for achieving the objective.

Tasks	Objectives	Design/System Trade-offs	Systems Requirements	Status
Timeline (10%)	• Agility for mission completion in the stipulated time. • Optimized post-processing Algorithm. • Quick Setup/Teardown time	• High thrust which might result in increased probability of structural failure • Computational Ability by Ground Station System. • Modular components which reduces structural discrepancies.	• Automatic waypoint upload which reduces the pre-flight time.	-
Autonomous Flight (20%)	• Sustained Autonomous Flight • Waypoint Accuracy	• External Integration of sensors for autonomy which reduces available area.	• Autopilot System (Includes Flight Controller, GPS, Compass and Telemetry)	Will be attempted Priority : 50%

Obstacle Avoidance (20%)	• Optimized obstacle avoidance algorithm	• Increased computation time in ground station	• Ground Control Station	Will be attempted Priority : 35%
Object Detection, Classification, Localization (20%)	• Rapid post-processing • Efficient Search Area Algorithm	• Speed of flight is lesser in order to capture high quality images.	• Camera, Gimbal and on board computer	Will be attempted Priority : 15%
Air Drop (20%)	• Optimized Actuator-Trigger for Air Drop	• Increased weight and circuitry for Air Drop Mechanism.	• Servo Drop System	Will not be attempted
Operational Excellence (10%)	• Structural Integrity • Attention to Safety • Implementation of Fail safes	• Additional man hours spent for increased safety, structural integrity and fail safes.	-	-

Table 1 : Mission Requirement Analysis

1.2 Design Rationale

The team designed The Eclipse keeping several parameters in mind during the design, development, and construction of the UAS. Some of these include its thrust to weight ratio, flight time, temperature and speed of flight. The main objective, in order to achieve maximum points in mission demonstration, was to develop a high precision autonomy system. The development team consisted of students of different majors, including Electronics and Communications, Aerospace, Computer Science and Mechanical Engineering. Students worked in teams dedicated for each subsystem. As the team was experiencing monetary constraints, the choice of durable, optimum high-quality components was critical. This also ensured that each and every subsystem was logically designed, eliminating technical flaws in any given aspect of the UAS. These decisions also guided the team with respect to the tasks attempted, and the priority given to them. The flow of design process is highlighted in figure 2.

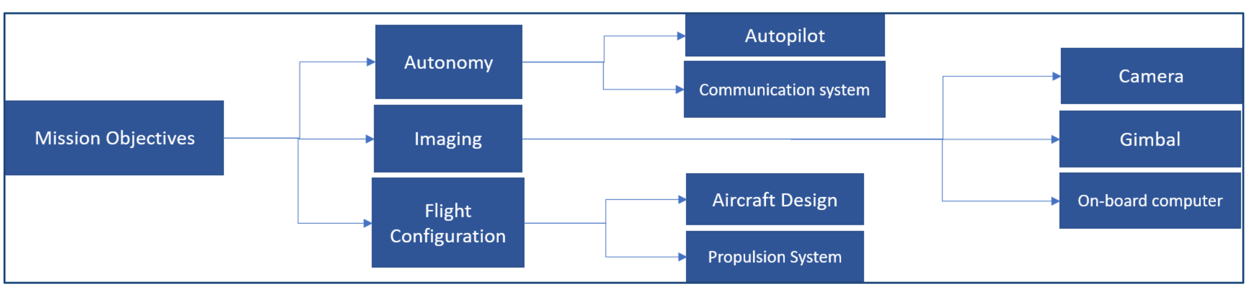

Figure 2 : Decision Process Flow

The key decisions taken were as follows.

1.2.1 Flight Configuration

For SUAS 2019, the team decided to continue with the hexacopter due to several factors. The first factor was the propulsion system redundancy. Fixed wing planes are more sensitive to hardware glitches which will potentially lead to more severe crashes. (For example: the likelihood of wing and tail breakage in a fixed wing is high even in case of minor fallacies). Additionally, stationary flight is not easily achievable using a simple fixed wing design and a hybrid design would involve complex aerodynamic design. Thus, a multirotor system was chosen due to its versatility and robustness. A hexacopter was selected since it satisfies the mission requirements better than the other multirotor

Design Criteria
Propulsion System Redundancy
Hovering Capability
Simple Aerodynamic Design
Good Maneuverability

Table 2

systems. For example, it provides more stability when compared to a quadcopter. In case of a motor failure, a hexacopter can be transformed into a quadcopter and can be landed. The hovering (stationary flight) capability of a hexacopter improves the payload drop accuracy. Battery replacement is easier, which is critical in performing long missions. Tasks like object detection and obstacle avoidance can be achieved with high accuracy and flying in tight spaces is much easier in a multi-rotor. Finally, the assembly, disassembly and portability supported our choice of a hexacopter over other types of UAVs.

1.2.2 Aircraft Design

The most critical part of a UAV carrying highly sensitive components is the airframe. It has to be light, structurally sound, and the base plate should not experience any vibrations from the six motors. Additionally, the payload must not cause extensive strain on the weak points of the frame. The design used this year is a customized Tarot T960 frame. This model offers innumerable advantages such as, detachable arms and landing gears, easier batteries replacement, and resistance to rollovers. The other improvement in the design is the arms. The arms go all the way to the center of the base which dampens the vibrations much more effectively. The choice of the skid type landing gear limits the drag of the UAV. It makes it comparatively lighter, easily foldable, conveniently portable and provides excellent strength during landing. This frame is superior in all aspects over the frame which was used by Project Jatayu in SUAS 2018.

1.2.3 Propulsion System

The team considered several motors of different ratings. The EMAX MT3515 650KV was initially tested. Although it was durable and could produce thrust to lift up to 2.8 kg, the flight time required was not met under the mission constraints. The motors also dissipated large amounts of heat, which was undesirable. To overcome this, the Tarot 5008 340KV Brushless Motor was chosen. This motor was readily compatible with the airframe, had a better design, and fit perfectly in the team's budget. It produced thrusts enough to lift weights up to 3.1 kg, which immediately improved in-flight stability and agility.

1.2.4 Autonomy

The autonomy system that performs waypoint navigation and obstacle detection, was of high priority to the team. The Pixhawk 2.4.7 was a very suitable choice due to its immense community support, along with its seamless integration with external sensors/systems. It's small form factor, weight and the processing of real-time data with its vast array of sensors helped in increased precision for flight stability and following the pre-defined flight path.

1.2.5 Imaging System

The imaging system of the UAS was considered to be another important decision point for the team, as the OLDC task requires immense precision and efficiency. The Sony HX90V was chosen as it had extensive support available. With 30x optical zoom coupled with a BIONZ X image processing engine, it consistently produces sharp, crisp images, which made target recognition very efficient, reducing post-processing time. This camera, paired with a 2-axis gimbal for image stabilization was a great way of achieving high quality images, with minimal distortions.

2. System Design

The complete design of the subsystems is described in detail below.

2.1 Aircraft

The Eclipse is built on a customizable Tarot T960 frame. The frame has a total span of 1000mm, and a 210mm x 210mm base plate area, which can house all required equipment comfortably. The batteries are placed on the top of the frame, allowing space in the bottom for the imaging system. The imaging system consisting of gimbal and the camera, is attached to the bottom base plate.

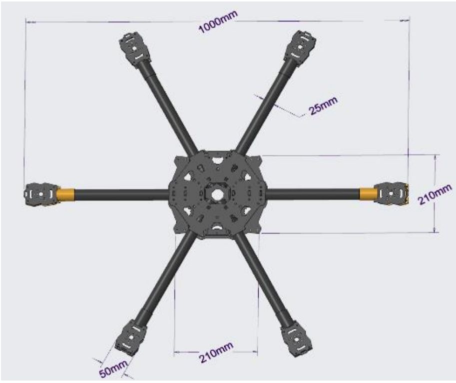

Figure 3a : Top View of Eclipse

Figure 3b : Front View of Eclipse

The frame is made up of carbon fiber which is light weight and rigid with high yield strength. This high strength aids in keeping the frame intact during small crashes. The frame is coated with an insulating material to avoid shorting of electrical components mounted on the frame. Additional aluminum plates are used to reinforce the base plate. The landing gear used is a CNC machined carbon fiber landing skid gear, which has high resistance to short drops.

Aircraft Properties					
Max speed	**7.5 m/s**	**Thrust to Weight Ratio**	**1.9 : 1**	**Total Weight**	**8468 g**
Operational Range (km)	**5 kms**	**Diameter with Propellers**	**1417 mm**	**Current at Max Throttle**	**27.07 A / Motor**
Max Flight Range (km)	**4 kms**	**Diameter**	**960 mm**	**Estimated Temperature**	**45°C**
Max Flight Time (minutes)	**21.4 minutes**	**Height**	**350 mm**	**Total Battery Capacity**	**24000mAh**

Table 3 : Aircraft Properties per set of batteries

The Tarot T960 frame is capable of withstanding the deformations under maximum thrust of 3kg. When the simulations were carried out on the motor mounts for maximum thrust conditions, the team obtained marginal deformations in the mounts. Although these deformations occurred for the maximum payload and takeoff weight, we obtained the Factor of Safety of 1.8.

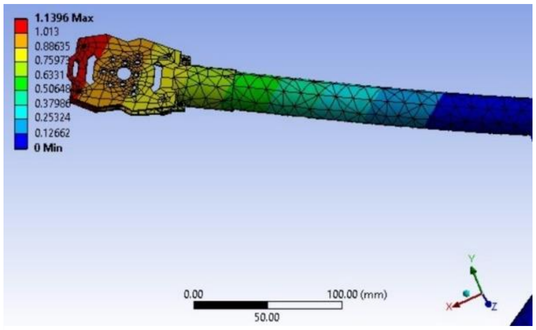

Figure 4a : Stress Analysis

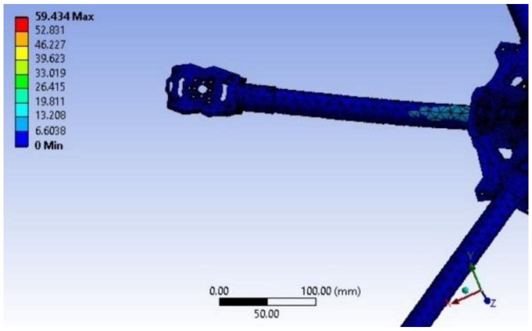

Figure 4b : Stress Analysis

Stress Analysis was performed on the joints of the arms when the aircraft was in hovering mode. The result turned out to be positive for the team, as the stress was negligible at the joints.

2.1.1 Propulsion System

Prior to choosing the motors, propellers and ESC, the team analyzed the requirements of the mission. Since the mission doesn't demand high speeds, motors with lower kV rating were required. The propulsion system of Eclipse uses Tarot 5008/340 kV motors. These motors provide low RPM and a high thrust which suits the mission requirements. For this motor configuration, the current drawn at maximum throttle is 27.07 A. This led to the choice of Hobbywing Skywalker 60A ESCs.

With the current choice of motors, which provides low RPM, the Eclipse required at least 17 inch propellers to provide sufficient thrust. To obtain a higher thrust to weight ratio, taking care of the inter motor mount distance, and current limitations, the Eclipse System uses 18 inch propellers.

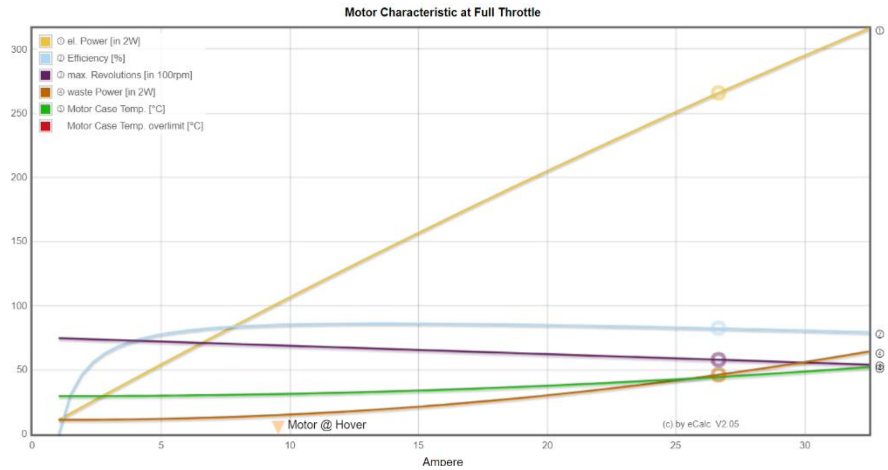

Figure 5 : Motor Characteristics

2.2 Autopilot

The autopilot system of the Eclipse uses the Pixhawk 2.4.7 from 3DRobotics as its onboard computer. The team tested the operational functionalities of flight controller boards including APM 2.8 , Pixhawk 2.1 and Pixhawk 2.4.7. These controllers were chosen based on their ability to perform autonomous take-off, landing and waypoint navigation.

	APM 2.8	Pixhawk 2.1	Pixhawk 2.4.7
Cost	₹ 2490.00	₹ 29,736.00	₹ 5950.00
Firmware	ArduCopter v3.2.1	ArduCopter v3.6.7	ArduCopter v3.6.7
Processor	Atmel's-ATMEGA2560 and ATMEGA32U-2 chips for processing and USB functions respectively.	STM32F302 / 72-channel U-Blox M8N engine	32 bit STM32F427 Cortex M4 core with FPU The 32-bit STM32F103 failsafe Co-processor
Sensors	● 3-Axis Gyro ● 3-Axis Accelerometer ● High Resolution Altimeter ● 5Hz GPS Module	● 3x Accelerometer ● 3x Gyroscope ● 3x Magnetometer ● 3x Barometer	● ST Micro L3GD20H 16 bit gyroscope ● ST Micro LSM303D 14 bit accelerometer/ magnetometer ● MEAS MS5611 barometer
System Support	● Mission Planner support is terminated ● Company and Community Support is available.	● Mission Planner support is available. ● Company and Community Support is widely available.	● Mission Planner support is available. ● Company and Community Support is widely available.

Table 4 : Comparison of Flight Controller Boards

Based on the comparisons discussed in Table 3, the Pixhawk 2.4.7 was tested and chosen for the Eclipse. The team decided to go with Pixhawk over APM because of the array of sensors available coupled with the extensive system and community support the Pixhawk provides. The Pixhawk 2.4.7 was chosen over Pixhawk 2.1 keeping the cost in mind.

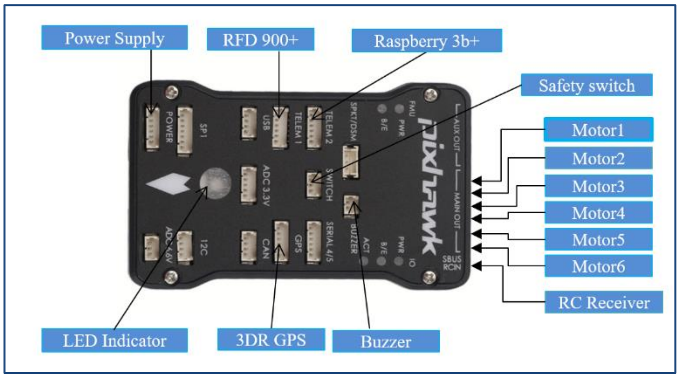

Figure 6 : Pixhawk Circuitry

The Pixhawk runs on ArduPilot 3.6.7 hexacopter firmware, which is open-source, designed by ArduCopter. The firmware includes predefined functions for autonomous take-offs and landings which assists the team to meet the mission’s objectives. The Pixhawk 2.4.7 also comes with an array of internal sensors including MPU 6000 as main accelerometer and gyroscope, ST Micro 16-bit gyroscope, ST Micro 14-bit accelerometer (magnetometer) and MEAS barometer. The presence of these internal sensors helps the team to reduce redundancy. This enables the autopilot system to perform autonomous missions including waypoint navigation.

The autopilot system is externally integrated with an U-Blox 7M GPS module which provides the GPS coordinates during flight with high accuracy. The onboard autopilot system communicates with the Ground Control Station(GCS) with the help of 900MHz RFD900 + telemetry which constantly transmits flight data including battery level, altitude, speed of flight, GPS coordinates and telemetry signal strength to the Ground Control System which the team uses to determine the safety of the flight and take decisions regarding manual takeover.

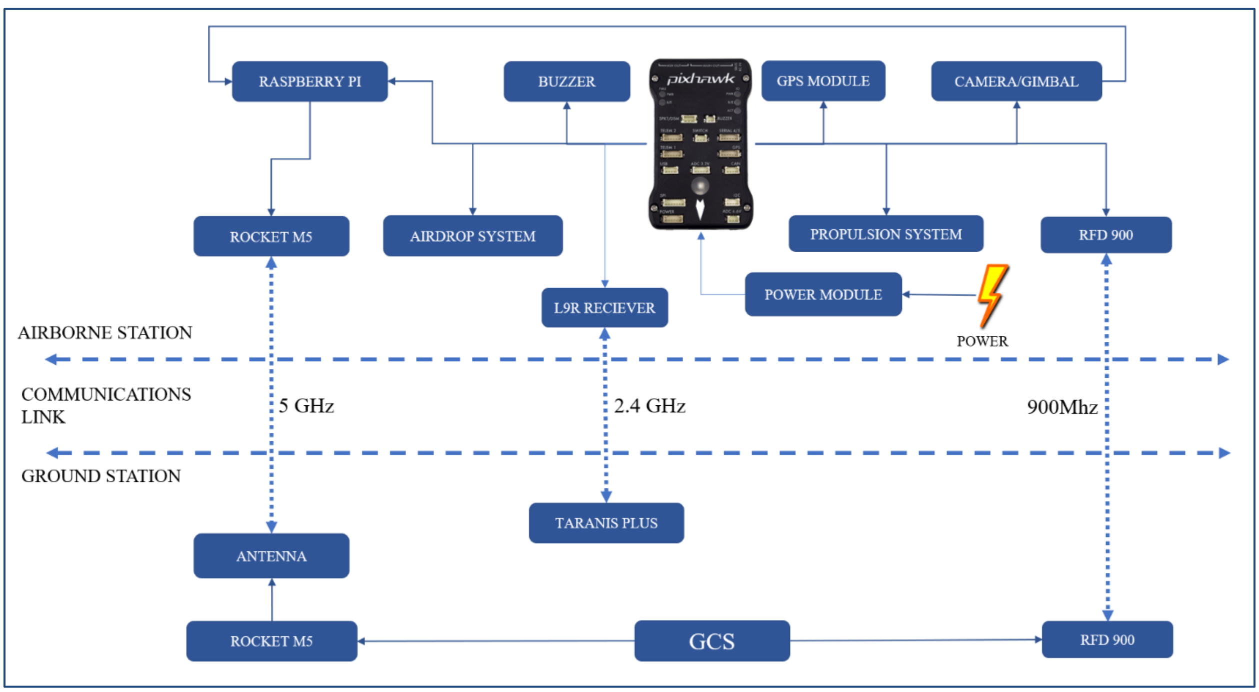

Figure 7 : Complete Block Diagram of Eclipse UAS

The autopilot system is connected to an onboard computer, Raspberry Pi 3, which along with a camera and gimbal for stabilization is used for the imaging system.

Ground Control Station: The Ground Control Station is totally split to perform 3 different tasks which are flight control, interoperability and ODLC System. The team uses 2 stations both communicating with each other to form a complete Ground Control System.

The team uses Mission Planner 1.3.58 as the primary GCS software. Its open source nature, along with the ability to easily receive flight data from the UAS led the team to the choice of this particular software. The mapping ability in Mission Planner enables the team to upload waypoints and also view the path the flight has to take, preflight, and perform the autonomy task with ease. The flight data can be monitored at all times using Mission Planner. Mission Planner also turned out to be a good choice for the team to perform the obstacle avoidance task as the team decided to modify the waypoints in order to enable the UAS to accurately avoid obstacles.

The Ground Control Station uses a Mavproxy connection in the Ground Control System to transmit the data received on the Autopilot Communication link(900MHz) and the Imaging Communication link (5GHz). The data received from the Imaging Communication link would be transmitted to the secondary GCS which is used to complete the ODLC task. The information from the Secondary GCS coupled with the flight data from the Primary GCS(Data from Autopilot Communication link) would then be parallelly sent to the Interoperability server which would then continuously receive data using a wired connection at 1Hz.

Figure 8 : Mission Planner GUI

2.3 Obstacle Avoidance

Avoidance of obstacle is done by altering the path of the flight at the places where obstacles may be present. This system employs a simple deviation in flight path where the original flight path intersects the obstacle. The Obstacle Avoidance algorithm is used to add a set of new waypoints which will be used to avoid a waypoint. First, the altitude of the obstacle is considered. If it is less than the flight altitude, the obstacle is treated as if it were not there. If the height of the obstacle is higher, the algorithm will draw a regular

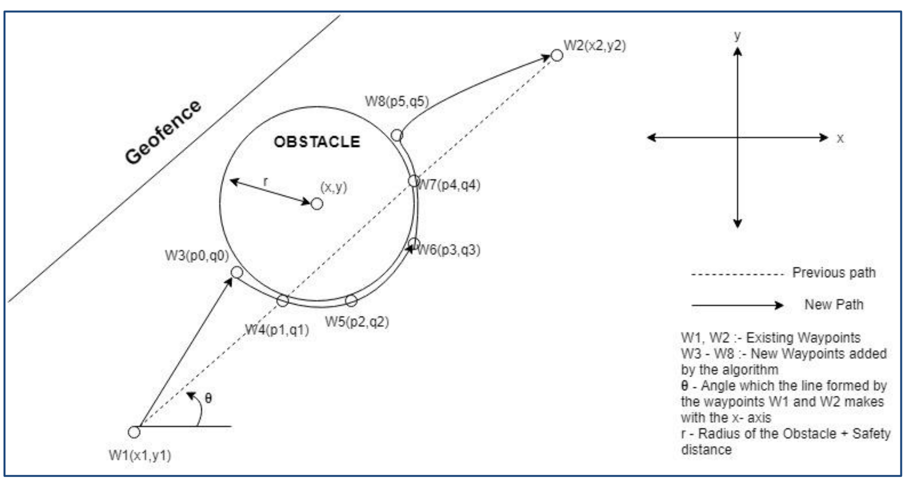

Figure 10 : Obstacle Avoidance Algorithm

$$s = 2r\left(\frac{\pi}{10}\right)$$
$$n = s\left(\cos\left(\frac{2\pi}{5}\right) + 0.5 + \cos\left(\frac{\pi}{5}\right)\right)$$
$$p_i = x - \alpha n cos(\theta - \theta_i)$$
$$q_i = y - \alpha n sin(\theta - \theta_i)$$

Where, $0 < i < 6$

(p_i, q_i) – *New Waypoint Added*

(x, y) – *Centre of the Obstacle*

s – *Side of the Decagon*

n – *Radius of the Circumcircle*

$$\theta_i = \left\{0, \frac{\pi}{5}, \frac{2\pi}{5}, \frac{3\pi}{5}, \frac{4\pi}{5}, \pi\right\}$$
$$\alpha = 1, if\ p_{i+1} > \pi$$
$$\alpha = -1, if\ p_{i+1} < \pi$$

decagon over the circular obstacle and the vertices of the decagon will be appended as new waypoints. These new waypoints added will then be input as spline waypoints in Mission Planner which will create a path for the UAS. This will approximately result in a path along the circumcircle of the polygon. This allows the team to provide a highly optimized path for the UAS allowing it to complete the mission in minimal time.

The algorithm also checks for the number of obstacles between two waypoints. If the number of obstacles is found to be greater than one, the algorithm generates a single circular object centered at the midpoint of the line joining the two obstacles having the maximum distance between each other and the new waypoints are calculated.
The algorithm results in two separate paths on either side of the circular obstacle. Of the two paths, the distance between each path and the boundary is considered and the path farthest from the boundary is chosen. Finally, the path chosen is checked for boundary breach, if detected, the obstacle is neglected.

2.4 Imaging system

2.4.1 Camera

To decide on a camera to mount on the aerial system, multiple factors were considered. To complete the ODLC task, primary features that are pertinent are image resolution and the search area. Other factors include the dimensions, shutter speed, weight and lens type. Another key feature to consider is the Application Programming Interface (API) support. The camera used in the previous year was Sony Qx100. However, it did not yield desirable results because 1) The picture quality was poor, 2) Bulky design of the camera. Taking these into consideration, the camera chosen is Sony DSC HX90V.

Feature	Sony DSC HX90V	Sony QX100
Battery Life	360 shots	200 shots
GPS	Built-in	No
Width of Camera	36mm	56mm
Optical Zoom	30x	3.6x

Table 5a : Camera Comparison

Parameter	Feature
Shutter Speed	1/2000 – 1/20
Aperture	F3.5-F6.3
MTP	Available at 480Mbps
Pixels	18.2 MP
Connectivity	Wireless + Wired

Table 5b : Specifications of Sony DSC HX90V

The API support provides various features that facilitate easy capture of images. It enables configurations like change in shutter speed, focus mode, and timed images among others. Based on calculations, it was found that an image needs to be taken every 2 seconds, in order to cover all the ground area and also perform processing on the on-board computer. The camera can be fitted onto the gimbal quite easily as it is both lightweight and small dimensions.

2.4.2 Gimbal

A two-axis gimbal is chosen. The camera is mounted onto the gimbal. The gimbal configuration is chosen such that it allows camera's roll and pitch to be controlled independently. Additionally, the 2 axis gimbal aids in stabilizing the camera and keeping it parallel to the ground at all times in order to facilitate capturing of pictures. Taking all of these factors into consideration, the gimbal chosen is Arris Zhaoyuin 2 Axis Brushless Gimbal. It has a firm camera installation and provides 360 degree unlimited rotation of pitch to provide flexibility.

2.4.3 Raspberry Pi

The on-board computer system must be capable of performing a multitude of tasks which include but are not limited to triggering camera action, image processing and establishing connection with the ground station. Thus, instead of a process intensive computer, a multipurpose system that can run multiple lightweight processes was desired. A Raspberry Pi 3B was chosen since it meets the criterion. The O-Droid that was used by Project Jatayu for SUAS 2018 was replaced since it did not provide wireless connection to a camera, which had to be achieved using peripherals. Raspberry Pi has an in built Wi-Fi module. It provides extensive multithreading support. It also has excellent community support.

2.5 Object Detection, Localization, Classification

The team's approach to ODLC is broken down into a series of well-defined tasks and steps. Based on the nature and the complexity, the tasks are distributed to be performed either by the Airborne station or the Ground Station. The code is written in Python and is designed to work on a Unix based system since the on-board system used is a Raspberry Pi 3B with a Unix operating system. It primarily employs OpenCV, a computer Vision library that provides real time image processing tools.

The steps involved are:

1. Preprocessing
2. Target Detection
3. Target Localization
4. Shape Detection
5. Character Extraction and Recognition
6. Color Detection

The workflow is described as:

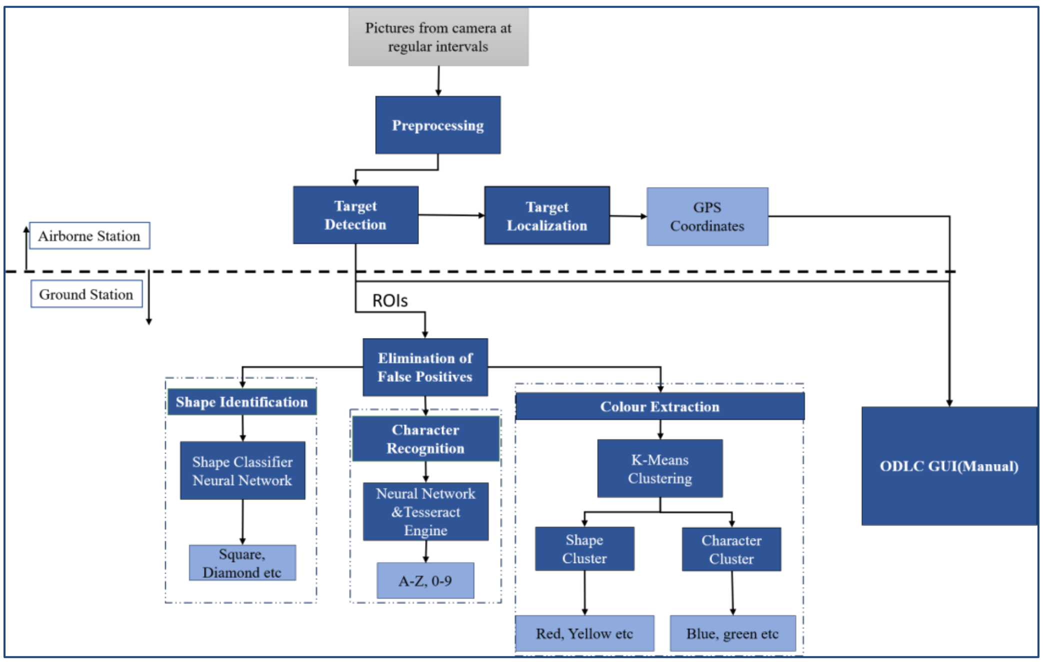

Figure 11 : ODLC Workflow

Airborne Station

2.5.1 Preprocessing

The image taken from the camera is preprocessed to remove noise and enhance localization. In the previous year, a K-Means algorithm was applied to segment and differentiate the target from the background. However, it did not produce promising results. Hence, focus has been shifted to morphological operations. A Laplacian 3X3 filter is used to sharpen the image since it highlights regions of rapid intensity change and can assist in edge detection. After

Figure 12a : Image before Pre-processing

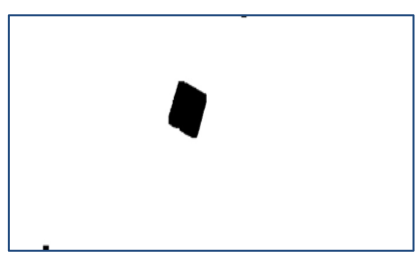

Figure 12b : Image after Pre-Processing

thresholding the black and white sharpened image, it is subjected to morphological operations. A morphological opening is applied to remove tiny noise and preserve the original shape. The shift to Morphological operations not only provides more accurate results, but also reduces the processing time drastically, which enables the algorithm to be employed on the Airborne station itself. This eases the burden on the Communication system to send only relevant data.

No of images tested on	41
No of images where Correct ROI Detected	39
Accuracy	95%

Table 6 : Test Results

2.5.2 Target Detection

After the preprocessing step, the Region Of Interest (ROI) is obtained by a 2 step process. Blob detection is first applied. A Blob is a group of connected pixels in an image that shares some common property. In Figure 13, the dark connected regions are blobs, and the goal of blob detection is to identify and mark these regions. After blob detection, the image is subjected to a contour detection algorithm on the Morphologically opened image. The algorithm returns multiple contours. Irrelevant contours are rejected based on their area and only the relevant contours are stored locally. If multiple contours are detected, all of them are stored. These are the regions of interest (ROI) of the image. The ROIs are sent to the ground station for further processing.

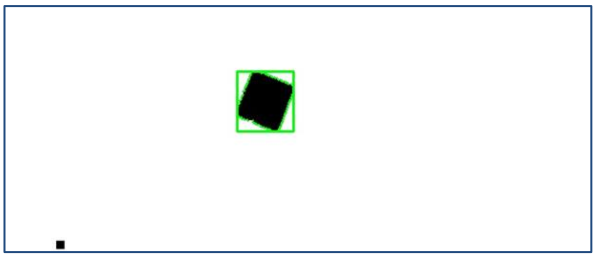

Figure 13 : Target Detection and Localization

2.5.3 Target Localization

The compass data and the GPS data are required for target localization. Target orientation is done in the ground station which will be described in section 2.5.5.3. After the preprocessing step, the Region Of Interest(ROI) is obtained by contour detection. The gimbal points the camera towards the ground for all objects within the geofence. The GPS coordinate of center of the image is obtained from the Pixhawk. Message acquisition is done through a serial to USB device connected to the RPi 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. To find the GPS coordinates of the ROI, a pixel-to-distance algorithm is applied, which is as follows:

1. Let the center of ROI be vector $A(x', y')$. Let the center of the image be vector $B(0,0)$.
2. The pixel distance between the vectors is d', and the angle between them is θ
3. Based on the altitude and the focal length, applying lens formula, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$. The distance of the ground covered is x in meters. The distance of the image that the ground covers is x' pixels, i.e. image size. Then $\frac{x'}{x} = m = -\frac{u}{v}$.
4. From Pixhawk, GPS coordinates of center of image is $C(x, y)$.
5. The distance of the ROI from center in meters is $d = d' \times \frac{x}{x'}$.
6. The GPS coordinates of the ROI is $C + cos\theta \times d$.

In order to improve efficiency, the GPS coordinates are sent as metadata of the ROI image obtained from the previous section to the GCS. This removes overhead of sending this data separately.

Ground Control Station

2.5.4 ODLC-GUI

The ODLC GUI provides for manual detection, localization classification of objects. The code has been written in Python with a HTML/CSS front-end, and uses a Flask server. Target images are displayed in the GUI with the ability to navigate between images. It consists of a form to select the following parameters for the image displayed:

1. Alphanumeric
2. Alphanumeric color
3. Shape
4. Background color
5. Orientation

The ODLC data is posted to the AUVSI SUAS server on submitting the form and the page reloads with the next image. Submitted images can be deleted from the folder of target images.

In order to achieve high quality integration with the server, the client library has been used to integrate with the interoperability system. The interop module has been imported into the code to create a client object with the server URL, username and password. The data and image associated with the target are uploaded using the API functions available. The interop server admin webpage has been used to test the working of the GUI and view the submitted data.

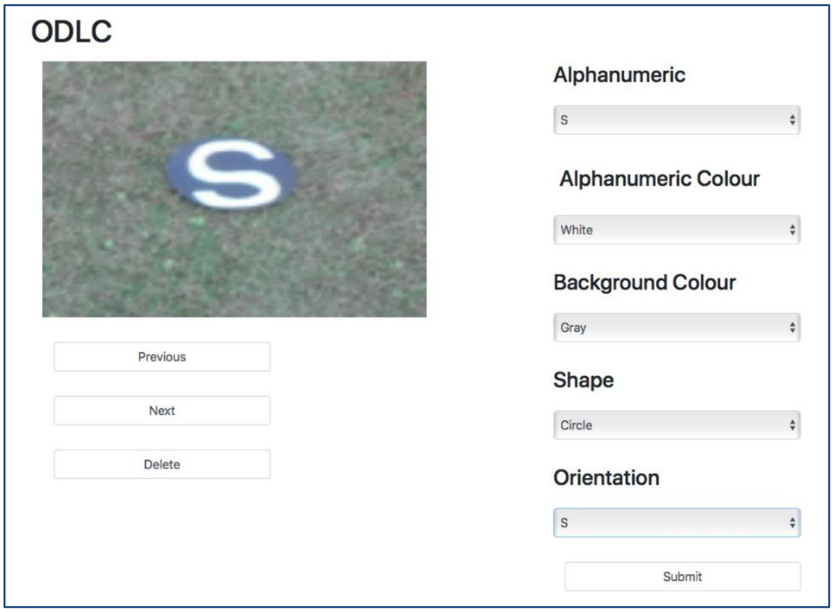

Figure 14 : ODLC Manual GUI

2.5.5 Autonomous Detection and Classification

This algorithm is employed to identify the foreground color, background color, the shape and the alphanumeric of the given target. This is done in multiple stages.

2.5.5.1 Elimination of False Positives

To eliminate detection of false positives, a simple Convolutional Neural Network has been trained that is a binary classifier. When an image is sent through the classifier, it predicts whether there is a target or not present in the image. The training accuracy of the classifier is 92%.

2.5.5.2. Shape Identification

This task is performed on the cropped image, that is obtained from the previous steps. A K-Means clustering is applied to the image to 3 separate color clusters (one for the background, one for the color of the shape and one for the alphanumeric). A shape classifier was trained using Keras and Tensorflow. The dataset was obtained from Kaggle which provided dataset for 13 shapes and all alphanumeric characters. A Convolutional Neural Network model was developed and trained, which fared well compared to naive thresholding and geometric calculations, which was done last year. The accuracy obtained was 80%.

2.5.5.3. Alphanumeric Classification and Target Orientation

Using the same dataset as described above, an alphanumeric classifier was trained. The output, i.e. the alphanumeric character is obtained. Additionally, the image is also fed into a Tesseract Optical Character Recognition (OCR) engine. The output obtained is compared with the previous output and the one with the highest confidence is chosen.

The accuracy obtained was 85%. Target orientation is also performed in this section. Alphanumeric character recognition is also used to identify the orientation of the target. Confidence scores for characters are checked and stored. The orientation of the character with the highest confidence score is selected. The angle made by the autonomous system, obtained via the flight controller, is subtracted from the orientation of the character with the highest confidence. The resulting angle is then returned as the orientation of the character.

2.5.5.4. Color Extraction

The cropped images are converted to a HSV color space. HSV is better at identifying color because it is invariant to changes in illumination. HSV color space is used mainly due to its ability to separate image illuminance from color information.

The image has 3 clusters as mentioned. The shape cluster and the character cluster are fed separately into the algorithm. The pixel values of each cluster are directly converted to their corresponding colors in the HSV color space.

Task	Accuracy Obtained
ROI Extraction	95
Shape Identification	80
Alpha-Numeric Classification	85
Color Extraction - Foreground and Background	83
Elimination of False Positives	92

Table 7 : Results for ODLC Task

2.6 Communications

2.6.1 Communication between the Airborne System and the Ground Control Station

The UAS system comprises of 3 wireless links to establish communication between the airborne system and the ground station. Figure 7 shows the communication architecture in detail. The three links used for establishing communications between the UAV and GCS use:

- The **Taranis** TX link working at the frequency of 2.5 GHz allows for the manual control of the airborne system from the ground for the pilot in case of an emergency. The Taranis transmitter is present on the ground station while and FrSky receiver is attached to the airborne system to communicate with the transmitter.
- The **Telemetry** link for the autopilot is established with the help of RFD 900+ pair which work at the frequency of 900MHz. The radio provides reliable telemetry at distances up to 5 km (3 miles). The MAVLink packets are transferred via RFD 900 due to its reliability. MAVLink packets are lightweight header only packets which are used to transfer necessary data such as GPS location, current speed and heading of the airborne system. These packets are sent from the autopilot to the ground station to monitor the airborne system in real time. These packets are also directed to the Interoperability server.
- **Rocket M5**, having a range of up to 3 to 6 Km (2-4 miles), along with helical antennas are used to exchange data required for object detection and localization task. As computationally expensive image processing algorithms are not executed on the airborne station, the processed images, as explained in section 2.5.3 need to be sent to the ground station which has a higher computing infrastructure. The Ubiquiti Networks Rocket M5 are used which operate at a frequency of 5 GHz. At the ground station the M5 is connected to a pair of 12dBi helical antenna. Helical antennas are used due to their improved directivity, robust design and broader bandwidth over cylindrical antennas. This also ensures that the connectivity is independent of the orientation of the airborne system.

2.6.2 Airborne System

There are two independent communication channels present on the airborne system. The first communication channel is between the RPi and the Rocket M5. They are connected via ethernet connection between them. This communication channel is used to exchange the digital data required for the object detection and localization task. The processed images are stored in the RPi and then sent to the ground station via the Ubiquiti Networks Rocket M5. The second communication link is established when the RPi connects to the Wi-Fi generated by the camera (Sony DSC HX 90V).

2.6.3 Ground Control Station

The base station uses a NETGEAR AC1200 router to exchange information between the judges server and the ground station. The MAVLink stream established between the airborne system and the ground station is tapped and also forwarded to a separate port. The MAVLink packets are then forwarded from the newly created port to the judges server to monitor the UAS in real time.

2.7 Cyber Security

Ensuring that all communication channels are secure is key to protecting IP and therefore the team has taken various steps in order to maintain the integrity of the channels. Potential threats may include unauthorized access to imaging data, either from the camera to RPi link or the transmission to GCS. Other threats are unauthorized access to MAV packets sent by the autopilot providing telemetry data.

There are 4 communication channels as mentioned created at various points and consequently, each channel has been secured to thwart cyber-attacks by employing simple protocols. The following table describes the mitigation steps taken to secure the channels

Channel	Mitigation Steps
Wi-Fi between Camera and Raspberry Pi	The use of WPA2 security standard for Wi-Fi at 802.11b, which employs the advanced AES Encryption algorithm
Telemetry data through RFD 900	Encryption of MAVLink packets using RFD900, which employs AES Frequency hopping protocol in the radios
Ubiquiti Rocket M5 connection	WPA2 encryption is enabled through the configuration settings of the Rocket M5.
FrSky Transmitter Receiver	It is bound to the transmitter alone, so signal cannot be hacked. Only the transmitter can activate it.

Table 8 : Cyber Security in Communication Channels

Not only are the communication channels exposed to threat, the computer devices at either ends are also targets for unauthorized access. The stations must be protected to prevent additional access of control of the device. Security of the stations, both onboard and ground are also enforced, as described in the table below.

Device	Security Steps
On board Computer (Raspberry Pi)	Authentication is provided using an SSH connection to a static IP that is known only to the team.
Ground Stations	Communication is established using Wired ethernet cables, and configurations are set to enable only certain MAC addresses to access them.

Table 9 : Cyber Security for Stations

3. Safety, Risks & Mitigations

3.1 Mission Risks & Mitigations

Comprehensive testing and mission developments posed various risks for the team. The table 10 describes the risks and the decisions that the team has taken to tackle them. The team always maintained a pre-flight checklist which lowered the frequency of occurrence of the aforementioned possible failures that might have taken during flight. The team constantly updated its safety precautions based on the failures during testing.

Mission Risk	Frequency of Occurrence	Consequences	Mitigation and response
Telemetry failure	Medium	Flight data cannot be tracked by the GCS	• A buffer period of 20 seconds will be given for the flight to re-establish telemetry link. • If the primary response fails, the flight will switch to RTL mode.
GPS failure	Medium	Waypoint Navigation will be disrupted	• The flight will initially switch to loiter mode for a period of 30 seconds • If the GPS signal is still not recovered, manual override of flight by the safety pilot.

Low battery voltage	Rare	High Risk as the Flight might undergo a crash	• Land failsafe will be initiated when the battery voltage drops below 20.4V (3.4V per cell)
Structural vulnerabilities	Rare	Loss of Flight Stability	• The extent of vulnerability will be assessed at the GCS based on the stability of flight and the decision for manual override will be taken
Autopilot Failure	Rare	Flight of the drone will be severely affected	• Manual override will be immediately initiated
Ground control System power loss	Rare	Interop and ODLC system failure. GCS cannot control and track the Flight data	• GCS control will be immediately transferred to the secondary system which will run both the applications
Loss of Imagery Link	Rare	Real time image Processing at the ODLC system of GCS not possible	• The images taken after the loss of link will be stored on the onboard computer and be processed after mission completion

Table 10 : Mission Risks and Mitigations

3.2 Developmental Risks & Mitigations

For this year's competition, a complete predetermined analysis was done to examine the developmental risks and its associated mitigations.

Developmental Risks	Occurrence	Intensity	Mitigation Plan and Response
Personal Injury - Structural - Developmental - Biological	 Medium High Low		• Precautions like safety gloves, gas masks must be utilized. • Localized Zones assigned for soldering and mechanical processes.
Financial distress	Medium		• Dedicated sponsorship teams assigned to gather adequate funds.
Damage due to structural Defects	Low		• Pre-checks of components were done performed regularly.
Fire due to shorting or overheating	Low		• Carbon-Dioxide Fire Extinguisher kept close to workshop premises.
Battery Precautions	Low		• Polarities to be verified pre-connections. • Battery stored in a protective casing.

Table 11 : Developmental Risks and Mitigations

4. Conclusion

The team has worked extensively to ensure that Eclipse meets all the specifications prescribed by the SUAS 2019. An emphasis was specifically established on the improvements of the UAV compared to the last year's. A larger focus on individual component testing, image processing and communications were made based on the weightage of points. The team's experiences from the previous year's competitions have provided a platform to ameliorate and build confidence towards the SUAS 2019.