DELHI TECHNOLOGICAL UNIVERSITY

ABSTRACT:

Team UAS-DTU plans a comeback at SUAS 2017 completion with its UAS Lazarus. *It* comprises of a 2m wingspan airframe and an EPO foam body. Since the 2014 SUAS competition, the team has shifted from point and shoot cameras to android based smartphone primary imagery task. The system is capable of autonomously detecting static virtual objects and accordingly change its path, showing its obstacle avoidance capabilities. An open source mission planning software has been modified for providing interoperability, which was prioritized above all the other tasks. Paramount attention was given to the accessibility of sub-systems, which favored rapid prototyping and easier debugging. Live mission is observed at the ground control station. Risk and safety management were identified as high priority and were applied at every stage of the evolving design. This paper highlights the design rationale, development and testing procedures followed for meeting the established system requirements.

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1. SYSTEMS ENGINEERING APPROACH

The competition, apart from being a mission-oriented challenge which tests the technical advances made by a team, also scrutinizes its systems engineering approach. The team therefore outlined its systems engineering approach towards successful completion of the mission

1.1. Mission Requirement Analysis

The team carefully analyzed the mission tasks and identified the key areas where major developments were required. The sub-tasks were prioritized according to their respective weightage in their domain:

Table 1: Mission Requirement Analysis

Task	Threshold	Prioritized Task List
Autonomous Flight • Autonomous Takeoff and Land • Autonomous Navigation	waypoint off-set <100 ft.	1. Autonomous Navigation 2. Autonomous Takeoff Autonomous Land
Search Area Intelligence gathering • Target and characteristics detection • GPS Tagging with error	N/A Error<150ft	
Payload Drop • Deliver a Payload at a given spot without compromising the payload	Distance from bulls eye<150 feet and at least 80% water contained	1. Safe delivery of payload 2. Minimize the distance from bullseye
Interoperability operations • Download mission along with all data • Upload targets acquired in Search Area Intelligence Gathering Upload telemetry data	Refresh rate > 1Hz	1. Download mission and other necessary data 2. Upload telemetry at required rate 3. Upload targets acquired through Search Area Intelligence Gathering task
Sense, Detect and Avoid	N/A	1. Static Obstacle Avoidance 2. Dynamic Obstacle Avoidance
Mission Time	Flight time<20 min Post processing <20 min	

1.2. Design Rationale

1.2.1. Design and Development Model

A development model had to be chosen which could support rapid development and testing due to time constraints. The team's design rationale is based on a Rapid Application Development (RAD) model, a process of designing in which different components are developed in parallel as if they were mini projects, which helped the team to reduce the development time.

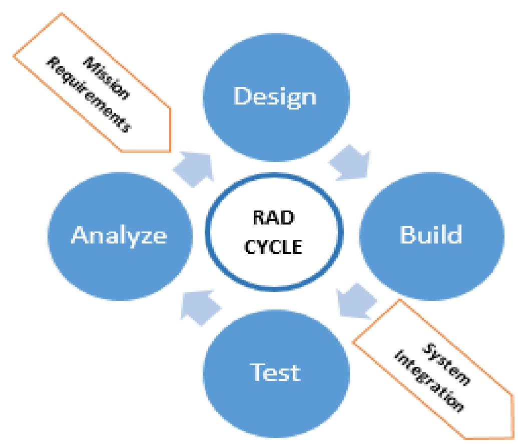


Fig 1. RAD Development Model

1.2.2 Air Vehicle Selection

The team shortlisted 3 air frames on the basis of experience in integration of a COTS frames.

Table 2. Airframe Comparison

Parameter	Units	Requirements	RMRC Anaconda	Finwing Air Titan	Skywalker X-8
Wingspan	mm	<3000	2060	2520	2122
Payload capacity	Pounds	>6	8	9	8
Payload volume	Cubic inch	>400	477	412	450
Take off/Landing requirements	-	-	Paved Runway	Paved Runway	Catapult, Hand Launched
Configuration	-	-	Conventional with Invert V Tail	Conventional with H Tail	Blended Wing Body
Cruise speed	Meters/sec	<18	14	12	16
Approx. Endurance	Minutes	>30	38	30	28
Cost	USD	-	$379	$390	$250

RMRC Anaconda had an edge over the other air frames in terms of size and payload capacity. It displayed commendable endurance performance. It was selected as the airframe for the sub-system.

1.2.3 Autopilot Selection

The team decided to shift from the earlier choice of PIXHAWK as a Flight Controller Board and decided to conduct a comparison between the APM 2.6, 3DR PIXHAWK and HEX PIXHAWK-2 based on their technical specifications as well as their suitability for the mission requirements.

Table 3. Mission Requirement Analysis

Features	APM 2.6	Pixhawk	Pixhawk 2
DIMENSIONS	35X35X5 mm	81x50x16 mm	94X44X17 mm
PROCESSOR	Atmel's ATMEGA 2560 and ATMEGA 32U (**No FPU)**	32-bit ARM Cortex M4 core with FPU	32-bit ARM Cortex M4 core with FPU
RAM	8 KB	256 KB	256 KB
MCU FREQUENCY AND FLASH SIZE	16 MHz; 256 KB Flash	168 MHz; 2 MB Flash	168 MHz; 2MB Flash
UPGRADEABILITY	Upgrades stopped	Frequent Updates Available	Frequent Updates Available
ROBUSTNESS	Low	High	Very High (Built in IMU heating system; Isolated and dampened IMU)
COST	65 $ (With GPS)	199.9 $	348 $

Comparisons between the three revealed that the PICHAWK 2 was better adapted to the mission requirements with its triple redundant, isolated and dampened IMU system; two onboard compasses and multiple GPS system providing reliable and accurate positioning and the robustness provided by the built-in IMU heating system and DF17 interface connectors. Thus, the team decided to choose the **HEX PIXHAWK 2** as its Flight Controller Board.

1.2.4 Imagery System

The use of mobile phone camera for imagery system was unprecedented in the team history. Previously, the team used Cannon G10 point and shoot camera, but better results were expected using the phone camera after analyzing the tradeoffs between the 2 type of cameras.

Table 4. Camera Comparison and Selection

Average Specifications/Class Of Cameras	Smartphone Cameras	P&S, SLR/DSLR Cameras	Rationale
Resolution(MP)	12-18.	14-30	15 MP determined to be most suitable since greater resolution resulted in larger file size
Equivalent Sensor Size(mm)	(28-31) x (14-16)	(21-35) x (14.2-16)	Larger Sensor resulted in a better field of view
Weight(in grams)	120-170	250-700	Smartphones had an edge in weight redundancy
Dimensions(in mm)	(135-156)x(68-73)x(6-9)	(110-160)x(60-110)x(50-90)	Lighter payload augments the mission time
ISO Range	100-1600	100-3200	ISO of near about 400-800 is preferred in sufficient light to avoid motion blur.
Shutter Speed Range(in s)	1/32-3	1/400-15	1/16 s shutter speed with 400 ISO for photography in ample light
Sensors internally Available	Barometer, Compass, GPS	GPS, Compass in some models	Barometer, Compass, GPS are favourable
Other Specs	OIS*, Autofocus, Back Illuminated Sensor etc.	OIS*, Autofocus etc.	OIS proved to be important in lowering the levels of jello effect
Processor Specifications	Quad-Octa Core, 1.8-2.7 GHz,1.5-4 GB RAM size	Single-Dual Core, 0.5-1.2 GHz, 512 MB of RAM	Better processor allowed the pre-processing on board and thus eliminating the need of an on-board processor.
Operating Systems	UNIX based Android OS	Proprietary OS, differs with brands	UNIX based Android OS have a larger community of developers and allows the whole process to be open-source
Availability	HIGH	HIGH	High availability crucial
Price(USD)	124-310	155-775	Price of budget smartphones and cameras

Highly favorable — Moderately favorable — Not favorable

**OIS-Optical Image Stabilisation

Evidently, selection of smart phone as the primary imagery payload was advantageous.

1.3 Expected Task Performance

The table below summarizes the team's performance during the flight testing and evaluation phase. A total number of 30 flights were conducted and the progress made in each task is as follows:

Table 5. Test flights performance

Task	Performance during test flights	Flight tests conducted	Status
Autonomous Flight	Full autonomous flight conducted	25	Will accomplish
Waypoint Plan Following	Waypoint navigation with 5 m off-set	22	Will accomplish
Search Area Intelligence gathering	60 % success rate with processed images	20	Will accomplish
Sense, Detect and Avoid	Static objects dodged with 45 % success rate	7	Will attempt
Payload Drop	Accuracy of 38 feet achieved	11	Will accomplish
Interoperability	Refresh rates above 4 Hz achieved	12	Will accomplish
Off Axis Target	Ground tested	-	Will attempt

1.4 Programmatic Risks and Mitigation

The Team listed and prioritized the risks that could have been met with during each stage of the preparation. The priority of the risks defines the amount of time that need to be invested on the mitigation of the risk. Likewise, the team has always emphasized on identifying risks affecting the project as a whole and formulated plans for their mitigation.

Table 6. Test flights performance

Risk	Description	Likelihood	Impact	Mitigation Strategy
Complete airframe loss	Loss of airframe during flight testing	Medium	High	An alternate airframe kept operational at all times with backup subsystems installed
Delay in Sub-system testing	Sub-system failure lead to postponement of scheduled flight	Low	Medium	A multirotor frame kept operational for fast deployment and testing images
Conducting test flight	Objection on conducting flights in the college premises after the announcement new D.G.C.A. rules for UAV operations	Medium	High	Timely approval taken from college authorities in accordance with the flight test schedule.
Sub-systems compatibility issues	Designed sub-systems not compatible in terms of size, software, or accessibility	High	Medium	Regular Inter-Department meetings for discussing the under development sub-systems and identification of multi-disciplinary failure points
Mechanical vibrations	Acquired images distorted due to jello effect making the imagery algorithms in-accurate	Medium	High	Development of anti-Vibration mount and incorporating it into the gimbal sub-system
Safety Pilot	Un-availability of a safety pilot directly affects the teams' ability to safely conduct a flight test	Medium	High	Training of select crew members as safety pilots before and during the flight tests

2. UAS DESIGN DESCRIPTION

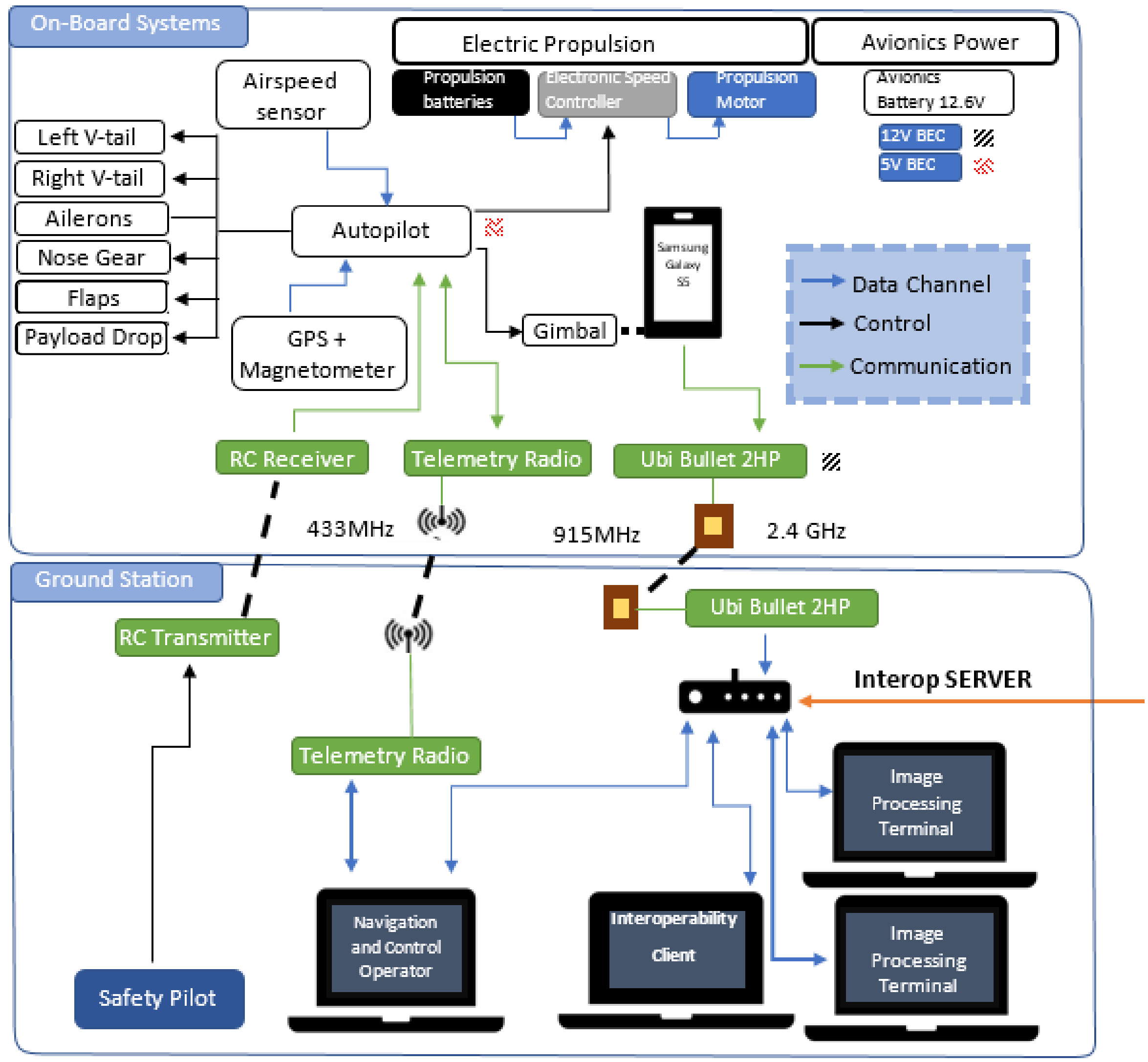


Fig 2. System Architecture

2.1 Airframe

Key requirements which were considered while selecting the airframe were high payload weight, long endurance flight, ample volume for payload, small takeoff distance ,easy assembly and repairability. The design rationale suggested Anaconda as the optimal airframe for SUAS 2017.

Anaconda is a twin boom, inverted V-tail pusher design. The frame sports an expanded polyolefin foam built body which allows quick modifications and repairs to the damages incurred during flight test.

Major modifications include the increment in the ground clearance of the frame for accommodating the camera gimbal and the payload drop system. A customized base plate for the fuselage was also fabricated for providing mounting solutions for the various subsystems inside

Table 7. Airframe specifications

Parameter	Specification
Wing span (m)	2
Max G.T.O.W. (kg)	5
Takeoff distance (m)	10
Maximum endurance (min)	35
Stall: cruise: max velocity(m/s)	11:16:20
Wind tolerance (kmph)	25
Propulsion motor	T-Motor AT 3520-5, 880 kV
Propulsion battery	16000 4S mAh

and outside the frame. This allowed exclusiveness between the avionics and airframes preparation procedures, making interdependency delays minimal. Critical parts of the airframe were strengthened using 120 GSM Glass Fibre so as to enhance the survivability of the frame during crashes.

A dedicated nose gear was designed for increasing the ground clearance of the frame as well as providing a smoother ground roll during take-offs and landings. Throughout the flights, the frame was keenly observed for wing fluttering, which is a sign of overloaded air frame. No such observations were made which led to the finalization of the Anaconda as the frame for SUAS 2017 competition.

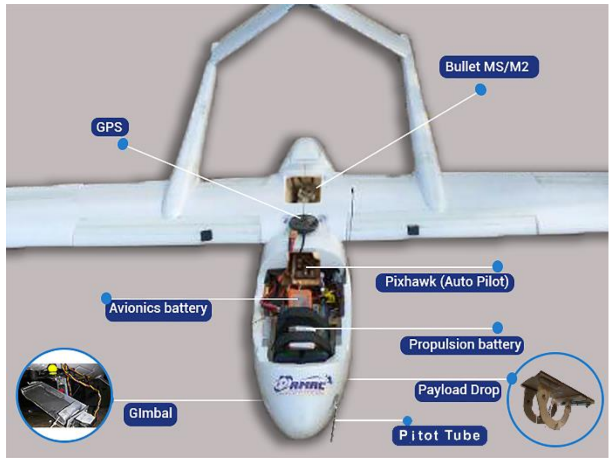


Fig 3. Aerial System

2.2 Propulsion System

The propulsion system of the Anaconda consists of a T-Motor AT 3520-5, 880 kV Brushless Electric Out-runner motor with a four cell 16,000 mAh Lithium Polymer battery. The motor used is a 1300 Watt rated motor on which thrust measurements were conducted on a test rig. An 80A ESC was found to be suitable with the propulsion system since maximum current drawn during thrust test was noted to be not more than 45 A. Thrust requirements were estimated by performing regular flight tests. The estimate of the endurance was taken by noting down the average Ampere-hours consumed after each flight test. This data was plotted against the flight time and after linear approximations, an endurance of about 35 minutes was estimated.

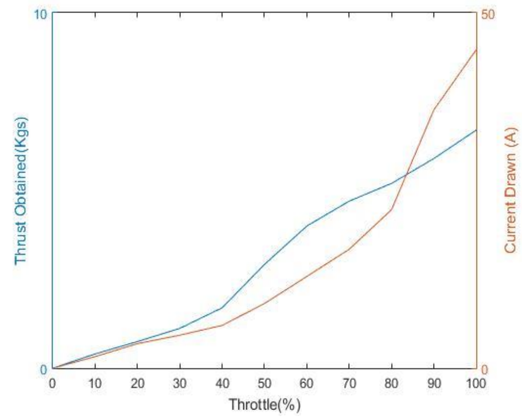


Fig 4. Throttle vs Thrust and Current curve

Moreover, a comparison between the thrust obtained at 4s 16000mAh and at 5s 5000mAh was carried out and it was found that they provided maximum thrust of 3.68 Kgs and 4.20 Kgs respectively. The former met the requirements and thus was opted for the competition. A mathematical estimate of the battery capacity was made as follows:

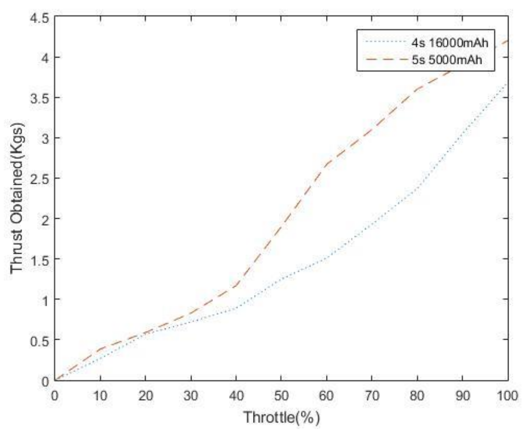


Fig 5. Comparison of 4s and 5s Batteries

$$\begin{aligned} &\mathit{Threshold\ Battery\ Capacity} \\ &\qquad = (\mathit{Current\ Drawn\ at\ full\ thrust} * \mathit{time\ for\ takeoff\ Routine}) \\ &\qquad + (\mathit{Currentdrawn\ at\ cruise\ speed} * \mathit{Mission\ Time}) \\ &\qquad = (45A * 20s) + (13A * 30min) = 6.75Ah \end{aligned}$$

2.3 Power Systems

The avionics system is powered by a 3-cell, 3300 mAh Lithium Polymer battery. The team decided to power control surface actuators with the same source due to little loading effects on five volts line through 5 volts battery eliminator circuit (BEC). The maximum power consumption of each component is displayed in table.

Based on the current consumption of each avionics component the endurance is estimated as below.

$$Avionics\ Endurance\ = \frac{Battery\ Capacity(Ah) * 60}{Maximum\ Current\ (A)}$$

$$Endurance\ = \frac{3.3 * 60}{1.97} = 100\ min$$

$$Factor\ of\ Safety = \frac{Calculated\ Endurance}{Threshold\ Endurance} = \frac{100}{30}$$

$$Factor\ of\ Safety = 3.33$$

Table 8. Power Consumption estimate

Avionics Components	Maximum Current Drawn (A)
Ubiquiti BULLET	0.583
Pixhawk 2	0.268
2.4 GHz RC Receiver	0.130
GPS Module	0.092
Telemetry Radio	0.053
Safety Switch	0.002
Battery Eliminator Circuit (BEC)	0.125
Elevon Actuator Servos	0.35
Landing Gear Servo	0.12
Camera Gimbal Servos	0.25
Total	**1.97**

2.4 Autopilot Systems

The 3DR Pixhawk 2 is an open source autopilot is suitable for the academic, hobby and industrial communities. The correct combination of parameters, calibration and tuning, can provide with the required results with high accuracy.

2.4.1 Software in the Loop Simulation (SITL)

Before actual testing on the frame, various software systems were tested in a software-in-the-loop simulation using JSBSIM, an open source Flight Dynamics model. All changes made to the source code as well as the code for the Interoperability system and Object Avoidance were tested in a flight simulation prior to actual flight. The Flight Simulator also helped to simulate events such as loss of RC Downlink and various weather conditions which helped in error reduction and smooth and safe operation of flight.

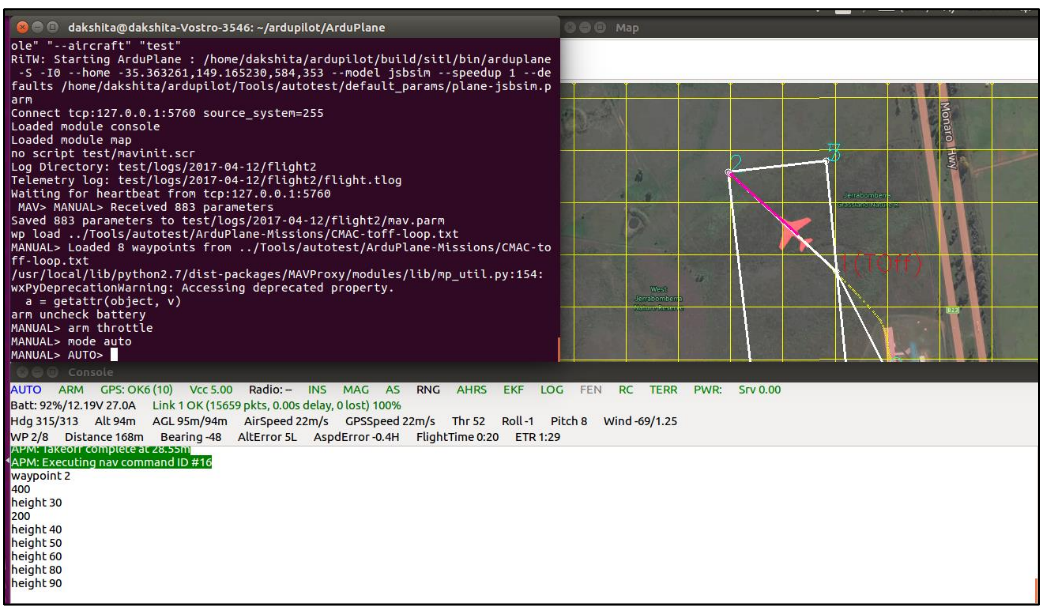


Fig 6. Simulation of a test mission in JSBSIM using SITL

2.4.2 Control Law and Navigation Tuning

Aircraft tuning being a necessity for autonomous flight was extensively carried out during the initial phase of preparation. Auto-tune mode of the flight controller was used in order to initially coarse tune the plane within the safe flying limits. PID tuning of roll, pitch and yaw loops was carried out later by giving extreme left and right rolls, up and down pitches and left and right yaw via RC iteratively. The fine tuning was followed by Navigational loops tuning improving the waypoint tracking accuracy and minimizing snaking effect. Throttle and cruise speed were also effectively tuned in order to make sure that maximum endurance can be obtained. Finally, Total Energy Control System tuning was carried out to increase the power efficiency while ascending or descending altitude, further, improving the endurance achieved.

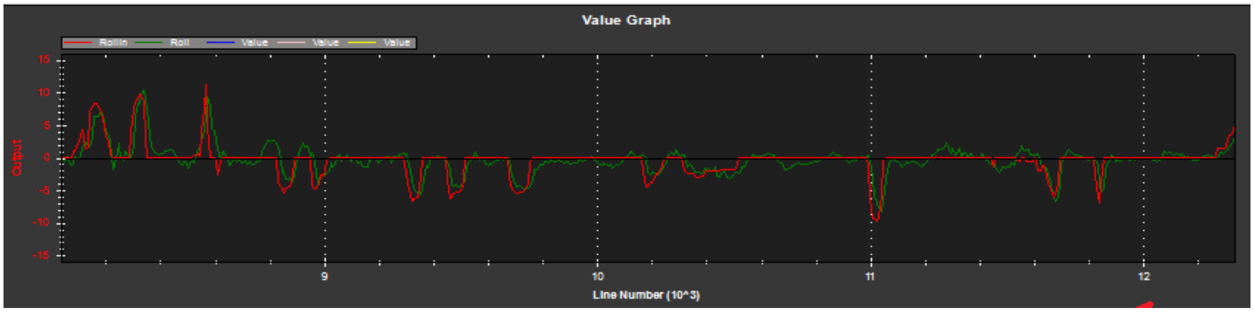


Fig 7: Roll tuning logs of the aircraft

2.5 Gimbal Sub-system

To point the camera towards the ground during the mission, a 2-axis, servo actuator based, roll and pitch gimbal was conceptualized and developed. Special attention was given to the maximum roll angle attained, as it directly affected the off-axis target capture algorithm. Light material like aluminum, wood and composites were used for the fabrication.

The camera gimbal is controlled via the autopilot which generates signals for the phone to always face the nadir point counteracting the air vehicle orientation.

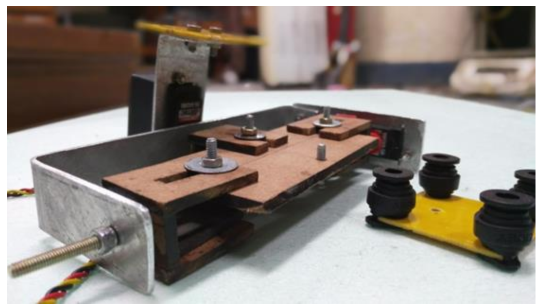


Fig 8: Camera Gimbal

2.6 Communication System

The team utilizes three communication channels for continuous transmission of information to and from the Ground Control Station. Manual Radio Control: provides an overriding R/C access of the plane to the safety pilot in case of an emergency. A Futaba T10CAG RX-TX set enhanced by an Immersion EzUHF Transmitter module is used. The communication takes place at a frequency of 433MHz.Telemetry downlink and uplink is carried out to the onboard autopilot Pixhawk via a 915 MHz link with an output signal of 100 mW and Frequency Hopping Spread Spectrum capabilities. The imagery system consists for two **Ubiquiti Bullet 2HP** WIFI routers (One mounted on the UAS and another on GCS) connected over a frequency of 2.4 GHz for downlink of images captured by the On-board mobile phone used for imagery using 802.11 Wi-Fi protocol. An in-house fabricated Patch Antenna is used which has been thoroughly tested for range and transfer rates.

2.7 Ground Control Station

The GCS acts as the hub for the intelligence, surveillance, and reconnaissance (ISR) data generated by the unmanned aircraft's payload. The GCS uses two terminals run under the aircraft operator i.e. one running mission planner, another running the interoperability server connected to the former terminal via Ethernet cable. The pilot can closely monitor the UAV from the GCS. Under the payload operator, one terminal has all Machine Vision capabilities where imagery is received

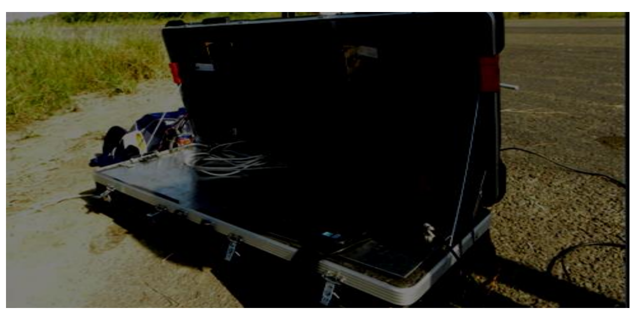


Fig 9. Ground Control Station

and final identified objects are submitted. The GCS contains safety equipment like fire extinguisher, safety goggles and other essential tools. The GCS was designed with a credo to provide a portable, integrated and rugged system, which can reduce the overall setup time for the UAV and increase the efficiency of the intelligence dissemination at each terminal.

2.8 Off-Axis Target Capture System

To capture the off-axis target, the stock gimbal stabilization algorithm needed to be augmented which when enabled, could calculate the instantaneous roll and pitch required to directly point at the off-axis object. The axis of the plane was taken parallel to the X-axis. With the center of the gimbal as the origin, a coordinate system was created. Using the GPS coordinates of the plane and off-axis object, distance between the two and bearing of the object with respect to the gimbal was calculated. This along with heading of the plane and altitude, the instantaneous roll and pitch angles were calculated to be run at a 20 Hz frequency in the Ardupilot firmware. A range was chosen under which the off-axis image capturing would start (ground distance-330 feet from the plane position). At all other times, the gimbal would capture images as per the stabilize mode.

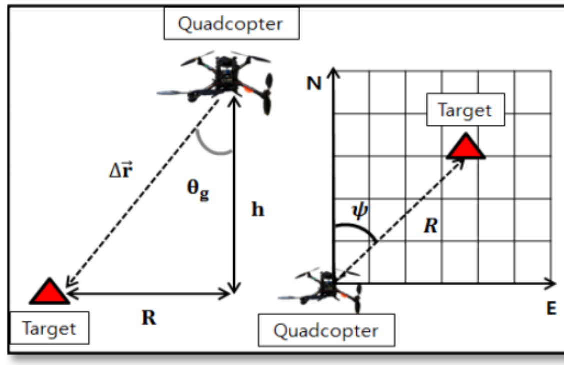


Fig 10. Angle calculation for Off-Axis Target

2.9 Payload Drop System

The payload drop task entails dropping an 8 oz. water bottle at a provided GPS location such that 80% of water content is retained. The mechanism is integrated on the outside of the air vehicle so as to preserve useful volume. The payload was covered with bubble wrap so as to endure the impact force during the drop.

An algorithm was developed which calculated the ideal GPS coordinates for triggering the servo of payload drop mechanism by considering factors such as surface area of the bottle, velocity, attitude, altitude of the vehicle etc. and then calculating the projectile range and comparing it with the distance between the vehicle and desired drop co-ordinates. The servo would be triggered within an acceptable buffer distance. This algorithm was integrated into the firmware of the autopilot. To ensure a safe drop, an enabling switch is provided so that the bottle is not dropped accidentally.

2.10 Imagery System

After a rigorous search and comparison, the team opted for a smartphone camera rather than the traditional Point and shoot cameras or a SLR/DSLR camera. The image quality of the smartphone cameras was found to be sufficiently detailed and sharp for further segmentation tasks, without the need for any enhancement or post development. The freedom to pre-determine the exposure, shutter speed, ISO, Burst mode interval, Image format and other parameters was just what the team was looking for to perform a flexibly sharp imagery.

The sensors of the smartphone i.e. the barometer, compass, the GPS, were found to be accurate enough to conduct the task with a suitable precision. The team also figured out that the relatively better processor of the smartphone device with the edge of being Linux based could perfectly be combined with the communication systems to eliminate the on-board processor, performing the primary processing on board itself. The various connection interfaces of a mobile device and the UNIX based open source applications made it perfect choice keeping in mind the aesthetics of the open source development. The mission objectives required an imagery system that automatically detects, localize and classifies (ADLC) the target in acquired aerial images in real time. The data processing unit was therefore designed to be reliable, efficient and fast.

The selection process and comparison of various smartphones has been depicted in Table 9. The colour of the cells indicate favourability green being most favourable and red being the least.

Table 9. Smartphone selection

Smartphone	Camera resolution (in mp)	Price (in usd)	Remarks
Samsung GALAXY S4	13	140	Moving Lens made it more prone to distortion due to mechanical vibrations
Samsung GALAXY S5	16	210	In photo comparison test , S5 had a better result than S4
Samsung GALAXY S6	16	545	Best Camera Among S4,S5,S6
HTC ONE M9	20	279	QUALITY INFERIOR THAN S4, Large file size
LG G4	16	387	COMPARABLE TO S4
ONE PLUS 3	16	418	Exceptionally good camera , comparable to S6, exceptionally good in low light
Moto G4 plus	16	201	Comparable to s4 , performs bad in low light

2.10.1 Autonomous Image Acquisition Unit

The images are captured using on-board mobile (S 5) phone camera which is controlled by an Android Application. There are three android applications used namely Open Camera (Open Source android application),FTP Server(Free Android application), UAS-T3(Locally Designed and developed Android App). Licenses of all the apps allow them to be included in the autonomous image acquisition unit, and the combination of all he apps allow the imagery system to capture images autonomously tagging them with related metadata and then relaying them to the ground in real time. The camera is two axis gimbal stabilized which counters the roll factor of the UAV and provides stable images. The Android Application controls the camera parameters and needs to be set before the camera is installed on-board. The application can be controlled remotely through an on-board computer, Banana Pi. It takes three seconds to capture two consecutive images, which ensures optimum overlap. As soon as an image is captured, the GPS is stored in the image metadata. These acquired images are simultaneously transmitted to the ground control station for processing via 5GHz data link provided by the on-board router. The image transfer takes about three seconds. This time interval proven to be sufficient for real time image processing within given mission time.

2.10.2 Graphical User Interface (GUI)

A GUI was created using the MATLAB app designer. It runs independent processes running on separate threads, reducing the execution time significantly. The GUI displays the images captured and potential targets present in the image. The various characteristics of the potential target is displayed with an option to either submit the data obtained or discard it. The details of all processed targets are stored in a SQL database common to all users. The GUI is capable of generating a text file for submission in accordance with the competition's requirements thereby reducing the mission completion time.

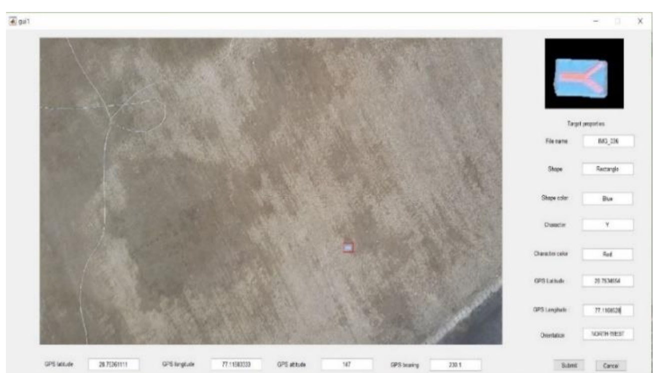


Fig 11. Graphical User Interface

2.10.3 Image Analysis

The team this year shifted to a combination of codes written in Matlab, python and C++ language, using the open-source library OpenCV 3.0.0. This unison of various algorithms allow faster processing of images and simultaneously checking the results to improve the accuracy. Total time to process an image was enough to process almost 300 images in mission time thus allowing the submission of results in real-time. Various image processing algorithms are describes below:

SHAPE RECOGNITION

Ray tracing technique was used to identify the shape of the target. This technique was found to be highly reliable and was improved for distorted shapes also. Once correctly segmented, the unit can now recognize various polygonal and non-polygonal images with 78% accuracy.

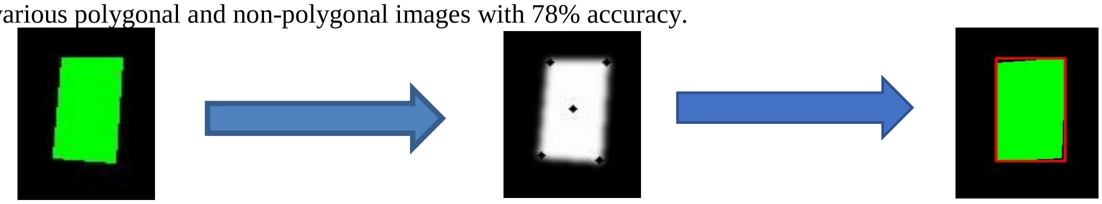
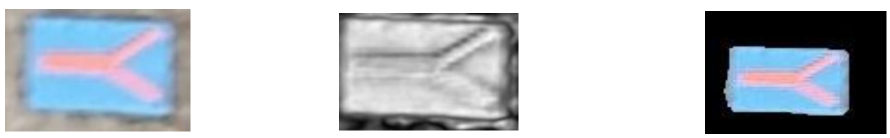


IMAGE FILTERING AND TARGET SEGMENTATION

The target in the acquired image is filtered using mean shift filtering technique. The smoothened image in output reduces the algorithmic complexities in segmentation of the target

The segmentation is found to be the most crucial part for autonomous recognition and classification process. A frequency tuned approach of segmenting to extract salient objects is used to segment targets from the images. The result of this is a grayscale image in which only the salient objects (probable targets in our case) appear white. The target is extracted from its background using a graph-cut based technique



Filtered image Saliency Map Segmented Target

COLOR RECOGNITION

Potential target image is first subjected to k-means clustering with four clusters. Four clusters are chosen to represent image background color, shape color, character color and shape boundary color. The cluster having second largest number of pixels gives the color of shape and third largest gives the character color. This value is then compared with a predetermined list of **HSV** values for mapping to the correct name.

K-means clustered image

CHARACTER RECOGNITION

From the k-means posturized image, character is segmented on the basis of its cluster size and a binary image containing the character is created. The segmented character is then identified using a code that uses character templates to determine the nearest character it could match.

Extracted Character

GEOLOCATION OF TARGET

The GPS coordinates of the target needs to be accurately determined, for this we require phone's GPS coordinates, altitude and bearing which is time matched with the images using the log generated by UAS app . Using the GPS coordinates of the center, relative bearing of the target and the distance of the target from center, the GPS coordinates of the target is calculated using the Vincenty formula of Geopy library of python.

Fig 12. Image Analysis work flow

2.11 Inter-operability

The team divided the Interoperability System integration into two parts:

- Primary Interop - This included initial essential tasks required before the mission demonstration in the setup task assigned, which include:
  - Continuous upload of Telemetry data by converting and forwarding the MAVLink packages to the Interop server.
  - Getting Mission information and obstacle information from the Interop server and saving it as a binary file in the form of a 2D list so that it can be accessed by other scripts for autonomous data upload.
- Secondary Interop – This includes uploading of target images and it's corresponding Json file onto the Interop server along with other operation such as deleting and editing a target on the server.

To proceed with the task, the team made necessary changes to the Python script provided for Interop so that command based interface carries out all the functions for Primary Interop task and a GUI from secondary Interop task. At this point, the team was able to perform all the tasks using the Client class provided which gave a telemetry transfer rate of 4Hz. But, to improve the performance and reliability of the system, the team is working on the AsynClient which is already in the state of completion and testing.

2.12 Sense, detect and avoid (SDA)

Sense, Detect and Avoid task involves avoidance of virtual obstacle provided to the ground control station via interop server. This year the team is planning to attempt static obstacle avoidance in SDA task.

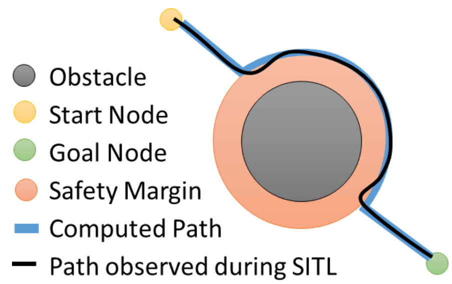


Fig 13. SDA workflow

A number of algorithms were considered and tested in order to make sure that an obstacle free efficient path can be computed within the required time constraints during the mission in order to avoid collision with any of the obstacles. Some of the algorithms that were considered include A*(A star), AFP (Artificial field potential) and RRT (Rapidly Expanding randomly exploring trees). The flight dynamic constraints made the task of planning all the more challenging because of the momentum carried by the plane and its inability to hover at a particular position. The team decided to use a hybrid of A* and AFP algorithms in order to ensure safe distance from obstacle during the path computation and to do away with most of the sharp turns.

Table 10. Algorithm comparison for SDA implementation

Algorithm	Merits	Demerits
A*	Shortest path, return message if no path exists	Path was composed of sharp turns and was very close to obstacles
AFP	Smooth trajectory suitable for fixed wing aircraft	Local Minima issue
RRT	Fast computation	Path calculated was not smooth and not suitable during search area task

3. MISSION PLANNING AND PROFILE

3.1 Mission tasks attempted

The team plans to attempt all the mission tasks in this year's competition except dynamic 'Sense, Detect and Avoid (SDA) and has tested them for the competition. To accommodate all the mission tasks in the targeted mission time, a complete mission profile was created with each task being completed in the expected time.

3.2 Mission Profile

On the basis of the sample search area provided, a simulated mission profile was created. The plan consists of the various mission tasks in the competition, the altitude of the UAS during each task and the time dedicated to each task. According to the mission profile created, the total estimated time to complete all the tasks is around 25 minutes with a buffer of 3 minutes.

Fig 14. Simulation Mission Profile

Safety is a major concern during UAS operation. At every step of UAS integration, starting from the design phase to the final deployment of the UAS safety regulations were the major concern of the Team. The degree of safety was based upon the number called "factor of safety" (FOS) which provided a safety margin for the design of all critical elements A higher FOS implied greater the safety margin and hence, more reliability.

4. TEST AND EVALUATION RESULTS

4.1 Developmental Testing

Subsequent tests were conducted during the construction of the system for studying the performance of the UAS and improvising accordingly. The following table depicts the mission testing plan adopted by the team :

Table 11. Mission Testing Plan

S No.	Task	Expected performance during flight test	Failure	Back-up Strategy
1	Autonomous flight 1. Takeoff 2. Waypoint Navigation 3. Land	 Comfortable takeoff within prescribed runway length Tolerable overshoot from waypoints during mission Suitable landing approach	 No lift-off within the take-off distance Way point overshoot>100 feet Landing waypoint overshoot	 Manual over-ride and forced takeoff Re-tuning of control parameters and re-attempt Manual over ride and re-attempt **if** battery levels are nominal
2	Air drop	1. Bulls Eye 2. Bottle doesn't break	Off-set > 150 feet bottle loses more than 20 % water	N/A Re-enforcing the protecting case for next attempt
3	SDA(static)	Virtual obstacle dodged	Collision with the virtual obstacles	Change parameters affecting the algorithm and re-attempt
4	ADLC	1.All characteristics of the captured images recognized 2. Geo location tagged with error <150ft	Geo tag error>150 feet	N/A
5	Inter-operability	Refresh Rate >5 Hz	Refresh rate <1 Hz	Disconnect and re-connect to the server

4.1.1 Mechanical Vibrations Test:

Since smartphones are lighter and smaller in size as compared to dedicated point and shoot cameras, they are more susceptible to mechanical vibrations, which tend to distort the captured images and makes the target detection inaccurate. To minimize the problem, a dedicated vibration isolation mount for the gimbal sub-system was designed and installed. It includes a combination of vibration isolating sorbothane balls and two composite fiber plates, which isolated the whole sub system from the fuselage. The graphs depict the magnitude vibrations felt by the phone with and without the isolation mount. It was observed that the anti-vibration system was able to reduce the vibrations from a value of 7m/s^2 to 1 m/s^2.

Fig 15. Target

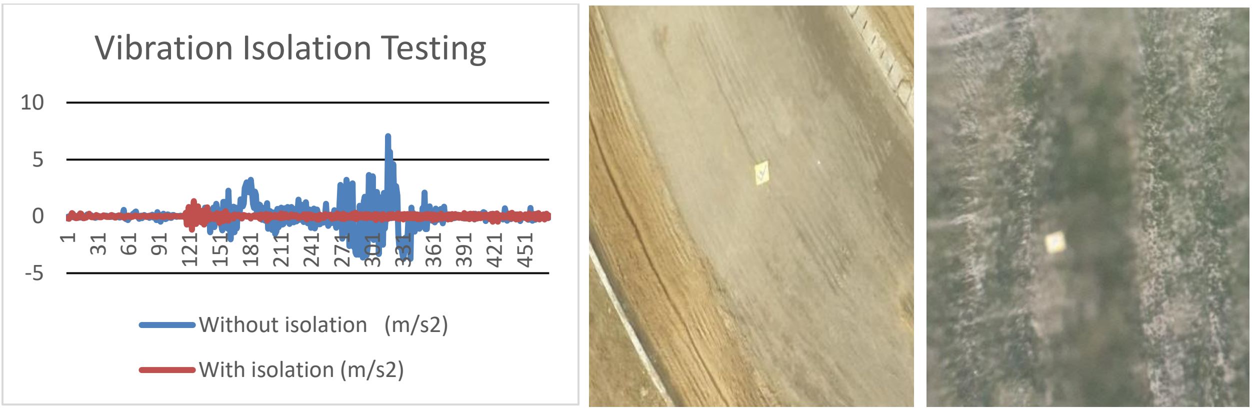


Fig 16. Vibration Isolation testing results (left), Vibration isolated image (middle) and vibration un-isolated image (right)

4.2 Individual Component Testing

4.2.1 Autonomous flight Testing

To control plane output to pilot input, extensive tuning was carried out on the frame to maximize performance. Auto flights revealed a waypoint following offset of 20 meters which was mitigated by carrying out navigation tuning which reduced the turning offset and resulted in accurate following of waypoint plan. Initial glitches in achieving a smooth auto-takeoff were countered by using TECS tuning which considerably improved auto takeoff and landing.

4.2.2 Payload Drop

4.2.2.1 Payload Drop Survival

Since the payload had to survive the high altitude drop, combinations of impact absorbing material were tested. Medium sized bubble wrap along with packing foam were selected due to the achievement of satisfactory results. Various drop attitudes were estimated and the covering was reinforced by adding extra bubble wrap and packing foam at positions of high stress , like neck of the bottle. . The drop altitude maintained for the tests was 60m,.The team will be attempting he payload drop from an altitude between 40-60 m

4.2.2.2 Accuracy

In the initial flights, the payload mechanism was tested manually. Once the algorithm was incorporated into the firmware, it was tested for 10 flight missions and an accuracy of 38 feet was obtained.

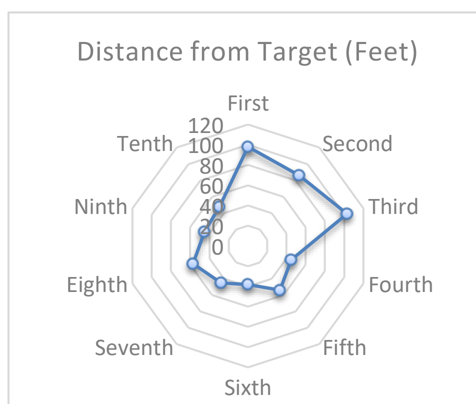


Fig 17. Payload drop test results

4.2.3 SDA

The dedicated script written for SDA task was tested several times on ground before being used in test flight for safety reasons. Interop server was set up to contain obstacles and mission waypoints, which were downloaded via the interop client and used to make an obstacle free path. The figure given below illustrates the path and waypoints before and after the implementation of SDA script. Further, the testing was also done via 'Software in The Loop' for verifying the sub-system.

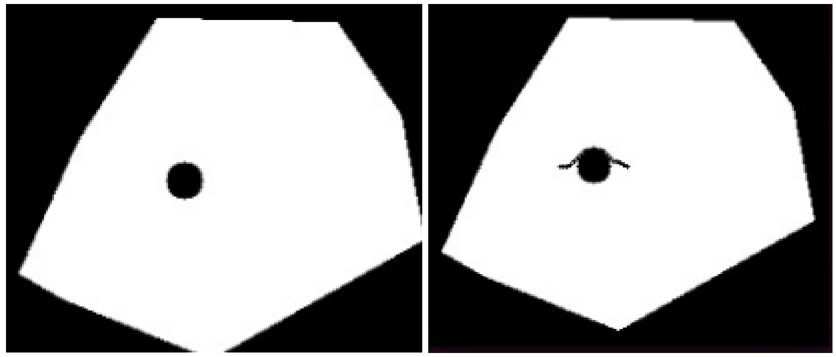


Fig 18. Occupancy grid (left) and generated path (right)

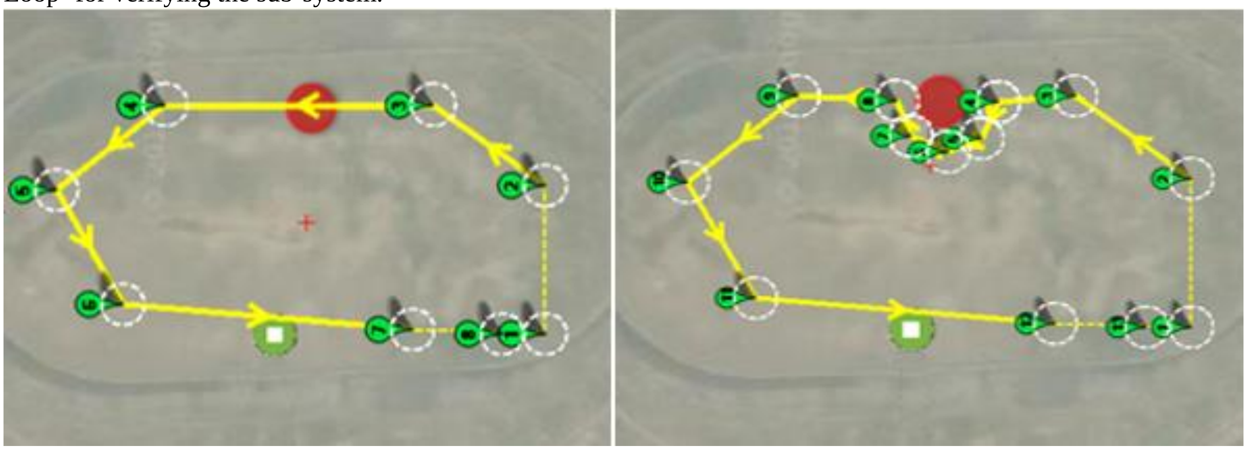
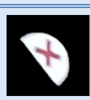
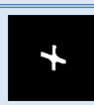


Fig 19. Waypoint plan before and after execution of SDA script (left and right respectively)

4.2.4. Imagery Testing

Once the mechanical vibrations were isolated, images were tested on a regular basis for various characteristics. The optimization of the algorithm was carried out as the number of flight increased. The images captured by Galaxy S5 from an altitude of 140 – 150 feet were found of sufficient image quality for the various data analysis tasks. The image data analysis system has been rigorously tested with different type of target shapes, alphabets and colours. The processing of an image roughly takes 4 seconds. The accuracy of the results would increase on the grounds with uniformity in grass cover and less pattern variations. The shapes that can be identified by the program autonomously include circle, semicircle, quarter-circle, triangle, square, trapezoid, pentagon, heptagon, octagon, star, cross.

Table 12. Imagery testing results

S.NO	SEGMENTED TARGET	EXTRACTED CHARACTER	SHAPE	SHAPE COLOR	LETTER	LETTER COLOR	GPS ACCURACY (m)
1			SEMI-CIRCLE	WHITE	X	RED	28.753280,77.115921 7 m
2			SEMI-CIRCLE	GREY	<	WHITE	28.753617,77.116038 6 m

3			QUARTER CIRCLE	BLUE	T	WHITE	28.754009,77 .117266 85 m
4			QUARTER CIRCLE	BLUE	Y	RED	28.75331,77. 116891 9 m
5			TRIANGLE	RED	H	PURPLE	28.752736,77 .116442 12 m
6			SQUARE	GREY	1	BLUE	28.750224,77 .116386 135 m
7			RECTANGLE	WHITE	M	BLUE	28.753203,77 .115640 11 m
8			CIRCLE	BLUE	N	RED	28.753895,77 .115826 17 m

4.2.5 Communication systems testing

To confirm reliability of the in-house fabricated antennas, CST simulations and ground testing were conducted on the 2.4 GHz patch antennas. The range of the communication system was tested on ground by increasing the distance between the station and the access point and observing the RSSI (Received Signal Strength Indicator) and ping delays. The data transfer rates obtained by the system were plotted with the distance between the GCS and the air-borne system. A minimum transfer speed of 0.5 MBps was obtained at a range of 235 m for which the mission shall continue effectively.

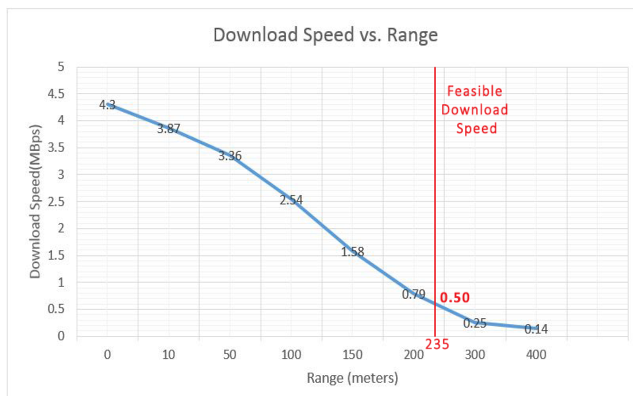


Fig 20. Communication system range testing results

4.2.6 Off axis Testing

The off-axis code provides instantaneous values of roll and pitch to be given to the gimbal servos as a PWM pulse for the time duration during which it’s enabled. Due to its substantial dependence on the plane GPS coordinates, which vary considerably, the PWM values vary rapidly and caused servo jittering. The frequency loops of computation were changed from a frequency of 60Hz to 20Hz in order to minimise the jittering, eventually removing it completely. The code was successfully ground tested by moving the autopilot and gimbal on a pre-planned route keeping the target’s location fixed in order to check whether the gimbal pointed at the correct location. A similar test was conducted by changing the altitude of autopilot rapidly in order to check whether the gimbal tilted as required or not. Test flights for the same still need to be conducted in order to achieve reliable results during flight.

5. SAFETY CONSIDERATIONS

5.1 Design Safety

The nose of the airframe, the nose gear along with the motor mount was strengthened to provide protection in case of a rough landing impact. The airframe was flown with dead weights as avionics, to check the airworthiness of the airframe. It was concluded that the frame is inherently stable, with good stall and landing characteristics due to presence of high lift devices, which deliver a smooth take-off and landing.
The camera mount on the stock airframe was located on the nose, but mounting a gimbal on the nose could damage the camera, in an event of nose down landing. Thus, the gimbal was placed behind the nose gear, which gave it protection. A vibration isolator was designed and installed on the gimbal which significantly reduced any vibrations to travel to the camera, and affect the quality and resolution of the images, giving improved results.

5.2 Operational Safety

A safe and secure system promises accomplishments. Thus, the team gives safety concerns a very thorough attention and follows well defined protocols during the flights to minimize risk.
Rigorous ground as well as flight testing of equipment was done. Every subsystem (landing gear, gimbal, payload drop, nose gear) is made functional, tested and optimised for efficient use.
A series of thorough pre-flight and post-flight checks of the system are done to ensure a safe flight. The crew makes safe the structure (joints and attachments are carefully secured), the control surfaces, the landing gear, subsystems as well as the static stability of the frame. It checks the transmitter & receiver feedback, battery levels, the autopilot functionality, propulsion, GPS, airspeed, reliable telemetry connection, servos, ESCs, GCS parameters and correct response of the control surfaces in manual and stabilise mode. The functionality of image processing algorithm, the battery level of the phone as well as the storage space on the device is also checked.
Safety equipment such as fire extinguisher, first aid along with food and water was carried at every flight. The safety officer ensures a stable, structurally strong airframe, making sure all the operative equipment function properly; along with checking the weather forecast for strong winds possibility or bad weather. The take-off and landing approaches are decided; the landing strip & airspace is cleared of any obstructions for take-off. Thus, personnel as well as aircraft safety is ensured and flights take place.
Prior and Post flight discussions would discuss the issues such as responsibility allocation, flight objective, conclusions of flights, improvements and aim for subsequent flights. To conclude, the safety operations for a flight were performed with stark sincerity and professionalism.

Table 13. Failure Mode Analysis

Failure Mode	Indication	Primary Response	Secondary Response	Tertiary Response
Telemetry Link Loss	Link Indicator Turns Red On MCC; Erratic Navigational Behaviour	If Link Between 60% And 80%; Mission Continued	If Link Less Than 60%, Switch To Manual And Troubleshoot Communication System	N/A
Image Acquisition System Fails	Image Synchronisation Fails/ Unresponsive	Reset Router Power; If Link Re-Establishes Within 3 Min, Mission Continued	Emergency Landing For Imagery Troubleshooting	N/A
R/C Link Failure	Actuator Response Time Increases; Erratic Plane Response	Automatically Shifted To RPV Using Autopilot Link, Mission Continues	R/C Link Established, Mission Continues	Telemetry Link Unreliable, Emergency Landing, Mission Stops For Troubleshooting

Mission Control Workstation Crashes	Workstation Hangs Or Shuts Off	Shift To R/C Meanwhile Backup Computer Brought In, Mission Continues	Mission Control Computer Ready, Switch To Auto, Mission Continues	
Battery Level Unsafe	Indicated On Ground Station	Battery Level Below Safe Level, Approximate 5 Mins Flight Left	Battery Level Below Danger Level, Shift To Manual And Emergency Landing	
Motor Cut-off	Continuously Falling Airspeed And/or Altitude	Chances Of Motor Cut-off, Switch To Manual Emergency Landing	N/A	N/A
Component Disintegration	Falling Debris, Erratic Behaviour	Emergency Landing; Mission Call Off	N/A	N/A
Imagery Terminal Crashes	No Output On Screen	Flight Continues; Backup Terminal Brought In	N/A	
Unable To Hold Altitude/ Enters No Fly Zone	Altitude Or Position Error Observed On the GCS	Switch To Manual; Mission Continues, Adjust Control Law Gains	Switch To Autopilot And Observe, Problem Rectified, Mission Continues	Problem Persists, Mission Continues

Code Blue: Mission Continues, Fully Autonomous

Code Yellow: Mission Continues, Manual Overrid

Code Red: Mission Haults, Emergency Landing

6. Conclusion

Unmanned Aerial Systems, Delhi Technological University has performed thorough engineering analysis for its UAS *Lazarus*, while adhering to its RAD developmental model throughout the process. This journal paper reflects the team's grasp over Systems Engineering and its earnest effort to achieve the level of fidelity that is required at SUAS. *Lazarus* after having completed 5 autonomous hours of flight despite 6 mild and 2 severe crashes equipped with reliable sub-systems complemented by a robust ground control station is capable of executing the designated task with precision, accuracy and reliability. The team looks forward to participate in SUAS 2017 and feels confident of a podium finish.

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