TECHNICAL DESIGN PAPER

UAS NMIMS

Journal Paper for 16th AUVSI Student UAS Competition

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Abstract

This paper describes the methodology used by team UAS NMIMS to excel at the mission tasks of 2018 edition of AUVSI SUAS competition. The team's primary aim was to design a fully autonomous platform which outshone previous year's system. Black Peafowl, a Hexacopter was developed by the team to achieve this aim. Black Peafowl was developed after rigorous development and testing on a test model. The development team of 20 members was an amalgamation of students from various engineering fields. Using all available resources and knowledge the team fabricated airframe, installed electronics, developed imaging system, designed air drop mechanism and tuned the autopilot with the airframe.

This paper gives a detailed description of the team's objectives in building the system. The paper also describes the UAS flight structure and concludes with a description of the testing that has been performed to ensure that each piece of the system is safe and reliable.

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1. SYSTEM 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 has thus designed an autonomous UAV to accomplish the mission tasks, outlined in the systems engineering approach.

1.1 MISSION REQUIREMENT ANALYSIS

The first step in the development of our UAV was analyzing the competition's requirements and its feasibility. This year the competition simulates emergency service of handling forest fire in which the mission related information will be received, the team will deploy its system which will fly to the search area, find the hints and the person of interest and then suppress the fire by releasing water on it. Table 1 describes the requirements of each mission task and what is required by UAV to complete each requirement (*assuming total marks for mission to be 100)*:

Task	Sub Task	Requirements
Timeline (10 marks)	Mission Time (8 marks)	To complete the mission within time we need to make an efficient flight plan and perform many test flights to achieve maximum marks.
	Time Out (2 marks)	To avoid any timeout, we need to complete the mission safely and within time.
Autonomous Flight (30 marks)	Autonomous flight (12 marks)	A minimum of 3-minute autonomous flight controlled through Autopilot.
	Waypoint capture (3 marks)	All waypoints need to be hit in a proper sequence and minimum distance from centre to gain maximum point.
	Waypoint Accuracy (15 marks)	UAV should capture the waypoints with minimum distance. Team should also be able to upload telemetry data throughout mission with 1 Hz frequency while airborne.
Obstacle avoidance (20 marks)	Stationary obstacle avoidance (10 marks)	Team need to use algorithm to create new waypoints on real time to avoid maximum obstacles in order to gain more points.
	Moving obstacle avoidance (10 marks)	Team is not attempting this task this year.
ODLC (20 marks)	Characteristics (4 marks)	Require good quality Image system along with image processing system to identity the Characteristics (Shape, colour, Alphanumeric). System should be able to detect manually and autonomously. Image should be geotagged with maximum variation of 100ft to get some points.
	Geolocation (6 marks)	
	Actionable (6 marks)	
	Autonomy (4 marks)	
Air Delivery (10 marks)	Delivery Accuracy (10 marks)	The UAV should hover over the target and its CG should be maintained after air delivery. Water must disperse at the location on impact.
Operational Excellence (10 marks)	Operational Excellence (10 marks)	Discipline, practice and safety is required.

Table 1 Mission Requirements

The team analyzed the requirements for successful mission execution which are enlisted in table 1. To stick with the timeline and to avoid timeouts the team has performed various tests flights and simulated mission tasks on the practice area to complete the mission within time. Regarding the Autonomous flight, we need an autopilot and airframe combination that can takeoff, navigate waypoints accurately and land autonomously. Since the team is upgrading its autopilot system, we have thoroughly tested and tuned our new airframe with the autopilot to be confident enough to accomplish the mission tasks. This year the team is attempting obstacle avoidance for the first time, which requires a system efficient at path planning. For this, we are using RRT* smart algorithm to accomplish the task, which avoids the obstacle by creating new waypoints. We won't be attempting Dynamic obstacle avoidance task this year due to lack of experience on the topic.

The Object Detection, Classification, Localization task requires a high-resolution camera, stabilization and data link to an image processing ground station. The team is using a separate system for image processing which will not interrupt any other communication between GCS and the UAV. The team is confident in the air delivery task which requires the UAV to maintain its Center of Gravity after the payload release and the release should be well timed for accuracy. Operational excellence requires all the necessary components, good sportsmanship, competent nature among team members and professionalism in mission tasks which the team has acquired through well-practiced mission simulations.

The team designed a new system, Hexacopter, for 2018 competition and team decided to the tradeoff in specific mission task respective of its weightage. Hexacopter was chosen to improvise airdrop making tradeoff with its flight efficiency and speed but was balanced with the selection of various component as described in the appropriate section and reducing the weight whenever its possible to increase the flight efficiency.

1.2 DESIGN RATIONALE

Team UAS NMIMS is a student team of 20 members. Out of 20 members, 5 are returning from last year and 15 are new members. This year's system was designed to maximize performance on the mission objectives. This section includes the factors and parameters depending upon which the design was finalized.

ENVIRONMENTAL FACTOR

The decisions made regarding the platform design addressed various environmental factors like Team qualifications, Time management, Manufacturing process, etc. *Team's qualification* implies in the evaluation of our capabilities in designing all aspects. Since *time* is of utmost essence, the project design must be feasible within the scope of the time that is available. The system should also be easy to *maintain* in order to minimize the preparation time between flights and increase the system's reliability. *Safety* holds a high priority in our design rationale so the system guarantees minimum risk, both for the crew operating it and for the system itself. The design shall be finalized considering the *area available* for the flight testing and feasibility of system's *portability*.

MISSION REQUIREMENT

The competition requires good battery autonomy, aerial photography capabilities, cruise speed, stability and excellent maneuverability. *Black Peafowl* was designed with four primary requirements: high portability, minimum cruise speed of 10 m/s, a flight time of at least 30 minutes and hover capabilities for accurate airdrop.

DECISION FLOW AND TRADE-OFFS

The system is designed to perform maximum mission tasks with utmost excellence. With the new design, the team has put its maximum efforts to attempt all the tasks excluding dynamic obstacle avoidance. The first step in design decision making was prioritising the tasks to be attempted by the team in the competition.

As per the mission requirements described in section 1.1, the first design decision was to select the most appropriate autopilot for an autonomous navigation system. The team decided to upgrade the autopilot system to Pixhawk 2.1 due to its high versatility, customization capability and high availability of compatible sensors along with broad community support.

The next decision was to select the camera for *Imaging System*. Sony A5100 was chosen to meet the mission requirements based on team's affordability concerning weight, frequency of images taken, quality, resolution and compatibility with onboard Odroid XU4.

Air Delivery was the next priority in design decision. The system was designed to have a hold and release mechanism such that the release of the payload should not disturb the stability of the system.

The following deciding parameter was to select the *networking requirements* of the autopilot and the camera. To fulfill this, an imagery data link and RF link were chosen to enable fast and accurate data transmission between the aircraft and ground station.

This year the team decided to go with a Hexacopter design keeping in mind the various environmental factors, hover capability, stable flight, high portability due to its folding arms and small area required for testing. Hexacopter provides us with more accurate air delivery and is cheaper to transport.

2. SYSTEM DESIGN

2.1 AIRCRAFT

AIRFRAME

The same system can perform differently on different airframes; hence the choice of airframe is essential for the system to work at maximum efficiency.

This year the team decided to use hexacopter for better performance in the competition. The team utilized the E-calc software to have an idea about the optimal battery, motor and propeller combination. All the combination were tested during the development phase as explained in later

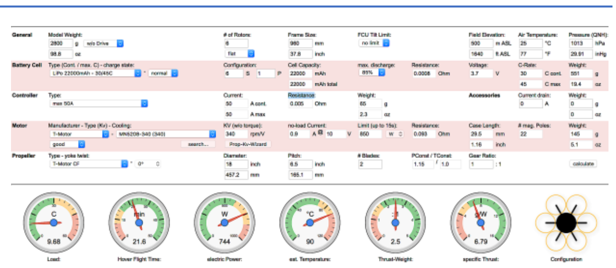


Figure 1 E-calc calculation

sections. Tarot X6 frame was modified after comparative study keeping in mind the mission objectives, team's requirement and available knowledge.

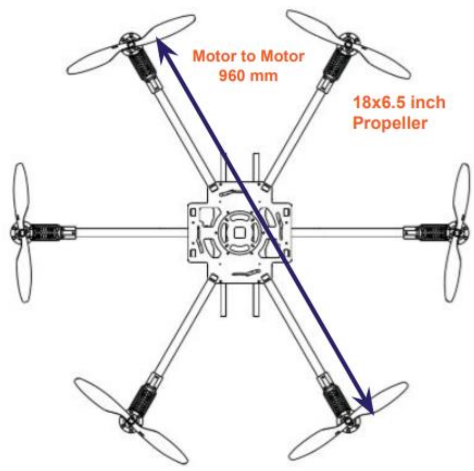


Figure 2 Competition Airframe

Aircraft properties	
Length (in ft)	3.149
Height (in ft)	1.049
Maximum takeoff weight (in lb)	22.046
Maximum speed (in knots)	19.04
Flight time (in min.)	35
Propeller size (in inches)	18 x 6.5

Table 2 Aircraft Properties

Modified Tarot X6 airframe was designed for carrying heavy payloads, with integrated PCB board for easy cabling and foldable arms for easy transportation. The low center of gravity battery mount is used for more stable flight. 6-motor design provides sufficient power even if one motor stops working unexpectedly, ensuring that the aircraft can land in stable condition. Airframe consists of six arms, each made of carbon fiber and supported by customized legs which assist the aircraft in achieving stable takeoff and landing. Apart from electronic components used by the team last year, new components have been added to the UAV while switching from fixed wing to multicopter to improve team's overall performance. Anti-vibration motor mounting set was made using CNC machining which dampened high-frequency vibrations from the motor. The airframe is thus designed for optimum airdrop, better imagery results, proficient waypoint capture and waypoint navigation.

PROPULSION SYSTEM

An efficient propulsion system provides good endurance to the airframe. The propulsion system includes motor and propellers (detailed later).

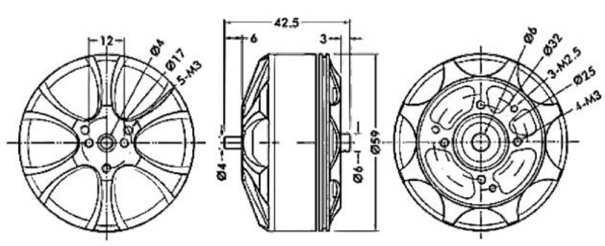


Figure 3 Motor Dimension

MOTORS

T-Motor MN5212 is chosen over others due to its lightweight, optimized thermal dissipation, precise assembling process, high speed of response, smooth functioning and perfectly balanced design which made it suitable for use in multi-rotors and ideal for our purpose.

Figure 4 T-Motor MN5212

AERODYNAMICS

To describe the dynamics of the hexacopter, assumed to be a rigid body, the Newton-Euler equations, that govern linear and angular motion, are taken into account. The net force acting on the hexacopter is provided by

$$F = \frac{d(mV_b)}{dt} + V \times (mV_b)$$

where the mass m is assumed to be constant. Every rotor *i* has an angular velocity ω_i, which generates a force fi = [*0 0* ω_i^2] being k the lift constant, thus the total thrust TB is given by TB = [0 0 T] ^{T} with

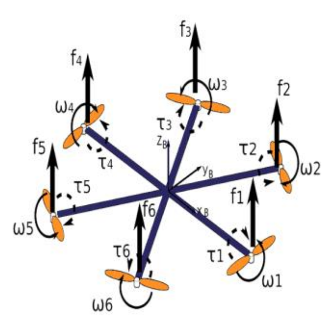


Figure 5 Forces acting on Hexacopter

$$T = \sum_{i=1}^{6} ft = \sum_{i=1}^{6} w_i$$

Total thrust together with gravitational force represents the total force acting on the hexacopter is $\boldsymbol{F} = \boldsymbol{Q^T F_g} + \boldsymbol{T_B}$

Let I be Inertia Matrix, the hexacopter has a symmetric structure with respect to the X_B-axis, Y_B-axis and Z_B-axis, thus the inertia matrix is the diagonal one I = *diag(Ixx, Iyy, Izz)*. As the total external moment M concerns, the rate of change of the angular momentum H = Iv is considered and the moment acting on the hexacopter is provided by

$$M = \frac{d(I_v)}{dt} + V \times (I_v)$$

Moreover, angular velocity and acceleration of the rotor create a torque of

$$\tau w_i = bW_i^2 + IM_i W_i$$

Around the rotor axis, where b is the drag constant and I_M is the inertia moment of the rotor *i*. From the geometrical structure of the hexacopter and from the components of fi and τ_{Mi} over the body frame, it is possible to get the information on roll, pitch and yaw moment, namely

$$\tau_{roll} = \frac{3}{4} kl(w_2^2 + w_3^2 - w_5^2 - w_6^2)$$

$$\tau_{pitch} = kl(-w_1^2 - \frac{w_2^2}{4} - \frac{w_3^2}{4} + w_4^2 - \frac{w_5^2}{4} - \frac{w_6^2}{4})$$

$$\tau_{yaw} = b(-w_1^2 + w_2^2 - w_3^2 + w_4^2 - w_5^2 + w_6^2) + I_M(w_1 + w_2 + w_3 + w_4 + w_5 + w_6)$$

Here *l* is the distance between the rotor and the center of gravity of the hexacopter and ω_i denotes the derivative of $\omega_i(t)$ with respect to time, i.e. $d\omega_i(t)/dt$.

PROPELLER-

While designing a fast flying multicopter, knowledge about diffrent propellers was must. Bench test was performed on the selected motor with various propeller size refer to *table 3*. 18x6.5 carbon fiber propellers were found to be the most efficient and light weighted. Carbon fiber propellers were chosen as they provide better efficiency and are long lasting.

Figure 6 18x6.5 Propeller

Propeller (Carbon Fiber)	Throttle	Amps (A)	Watts (W)	Thrust (G)	RPM	Efficiency (G/W)	Torque (in N*m)
16x5	50%	3.9	93.4	942	3767	10.09	0.187
	75%	11.1	266.2	2110	5565	8.29	0.405
	100%	21.6	518.2	3445	7296	7.28	0.66
17x5	50%	4.7	112.3	1095	3651	9.75	0.225
	75%	13.7	327.6	2363	5390	7.21	0.49
	100%	26.1	626.9	3716	6660	5.93	0.761
18x6.5	50%	5.7	137.5	1318	3596	9.58	0.29
	75%	16.5	395.5	2835	5226	7.17	0.605
	100%	31.0	744.7	4655	6358	5.85	0.918

Table 3 Bench Test Result

2.2 AUTOPILOT

To achieve the autonomous flight mission requirement, the aircraft needs to be controlled by an autopilot. The autopilot must be able to control the plane autonomously from takeoff to landing and be able to fly to predetermined waypoints.

At the start of the development period, the team analyzed possible autopilot systems. Two different versions of Pixhawk were considered by the team, Pixhawk 1 and Pixhawk 2.1 (cube). Last year, the team used the Pixhawk 1 autopilot to meet these specifications which worked very well with Skyking'17. This year, it was decided to upgrade the autopilot to the Pixhawk 2.1 for multiple reasons. Its IMU (inertial measurement unit) is now damped with triple redundancy to improve reliability in flight. It also supports up to 2 GPS for additional redundancy. The Pixhawk 2.1 is an affordable solution with a lot of functionality in a very small package. Additionally, it's enhanced Kalman filter can use data from the GPS and the barometer to fuse all the data and reject faulty measurements, protecting the UAV from problems such as GPS glitches and gyroscope drift.

The Pixhawk directly controls the ESC/motor for propulsion, the servos for the airdrop mechanism. In case a manual takeover is required, the team can use the Pixhawk's stabilize mode to control the hexacopter via the FrSky taranis R/C controller.

The Pixhawk also utilizes several sensors such as gyroscopes, accelerometers and barometers to maintain autonomous flight and telemetry data. The barometer is used with the external GPS module to determine altitude. On the Pixhawk, we run APM Copter 3.5.4 firmware. ArduPilot was the best choice for the Pixhawk since it is the most popular and stable open-source firmware currently available, provides great developer support and has many essential flight features required for autonomous flight as per mission requirements.

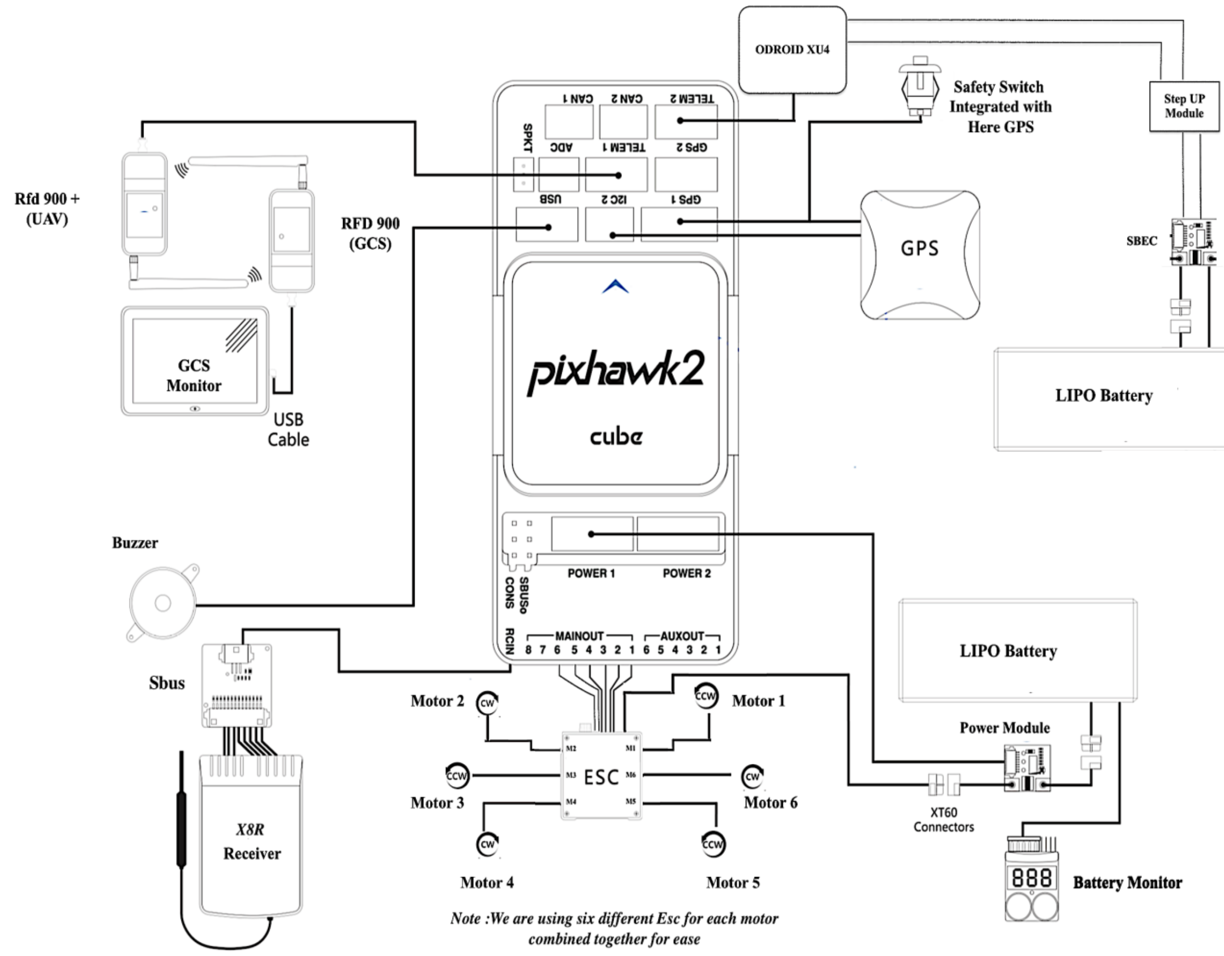


Figure 7 Autopilot (Pixhawk) Connection

During the development period, *Black Peafowl* has flown over 180 minutes in autonomous flight and more than 120 minutes in manual in over 25+ flights. Few parameters of the aircraft were evaluated during those flights and are presented in the *table 4.*

As mentioned before, the Pixhawk controls all the autonomous function of *Black Peafowl*, therefore it is critical to emergencies and to the mission tasks. In case of emergencies like unexpected loss of communication between the UAV and GCS (Ground Control System) , RTL (Return to Location) and other failsafe was also tested on the UAS.

Parameter	Value
MTOW at 50% throttle	7kg
Max cruise Speed	11m/s
Avg. Cruise Speed	10m/s
Max Flight Time	35 min
Max range tested	3 km

Table 4 Autonomous Flight results

Figure 8 GCS

The Pixhawk flight controller is synchronized with the Mission Planner software running on a GCS computer to give ground station personnel control over mission planning for *Black Peafowl* autopilot. Mission planner is an open source software which provides the opportunity to customize the software as per the requirement of the mission task.

It gives a great overview of all the autopilot's parameters, each with their complete description, possible settings and actual settings. It also enables us to adjust the tuning parameters for quick in-flight tuning of the system.

2.3 OBSTACLE AVOIDANCE

STATIC OBSTACLE

Figure 9 Before (Left) and After (Right) Avoidance

Team has designed an application which fetches the static obstacle avoidance data from interop server and creates the KML file, which displays obstacle on mission planner. *Black Peafowl* uses an extension of rapidly exploring random trees called the RRT*-Smart. RRT*-Smart is an extended version of RRT* and executes similar to RRT*, however it performs a path optimization process when an initial path is found. Moreover, it also identifies beacon nodes for path improvement which accelerates the path convergence and improves the path's cost. Further, it uses a Biasing Ratio to intelligently select either of Uniform Sampling or Intelligent Sampling. However, its Biasing Ratio is either manually set by programmer or can be automated using formula given below:

$$BiasingRatio = \left(\frac{n}{z_{free}}\right) * B,$$

where B = programmer dependent constant
n= dimension of given space
z_{free}= Region free from obstacle

For autonomous path-planning, team considered three path planning algorithms: RRT, RRT* and RRT*-smart.

Total Flight hour with SDA	**3**
Total static obstacle	**86**
Total static obstacle Avoided	**72**

Table 5 SITL SDA Test Results

Test results as described in table 6 shows RRT*-Smart expands tree rapidly as compared to RRT and RRT* because of its intelligent sampling and path optimization processes. Hence it generates shorter path in reasonable time using less dense tree thus saving the computational resources.

Parameter	**RRT**	**RRT***	**RRT*-Smart**
Path Cost (m)	56	50	41
Run Time (Sec)	150	621	210
Tree Density (No. of nodes in tree)	2954	2972	2000
Completeness	Probabilistic	Probabilistic	Probabilistic
Optimality	Non-optimal	Asymptotic Optimal	Asymptotic Optimal

Table 6 Comparison of SDA Algorithm

The method is tested through software-in-the-loop (SITL) simulation directly on the Mission Planner software as well as on competition aircraft.

This SITL technique allows not only the visualization of the trajectory by showing newly created waypoints, but also reduces development time through instant realistic feedback.

Furthermore, proper replication of the behavior of the plane allows for fine-tuning of parameters such as waypoints radius or max allowable climb rate before the competition. After SITL testing it was integrated into our system, on which the team conducted the rest of the flight tests, as shown in Table 5.

DYNAMIC OBSTACLE AVOIDANCE

The team is not attempting this task. As team decided to develop on a new frame it was a challenging task for members to analyse, acquire knowledge, experiment and test this development. Rather than focusing on this task, team decided to try and master in other task which are going to be performed in this year's edition of AUVSI SUAS.

2.4 IMAGING SYSTEM

High performance camera and exemplary imagery system is must for successful completion of all the above-mentioned task and missions in this year's competition. As a new frame was taken in consideration, all the test regarding imagery system and camera was performed again by the team. The team decided to shift from fixed wings to multicopter for better mission performance/accomplishment and thus different type of cameras were installed in the UAV. The camera is placed on center of gravity of multicopter on a mount with help of self 3D printed mold along with damper system to reduce the vibration effect on the images captured as shown in *figure 10*.

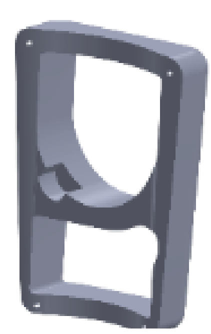


Figure 10 3D Printed Camera Mount

Test	Sony A5100	Nikon D3300
Compatible with Gphoto2	Yes	Yes
Resolution of target from Image	Yes	Yes
Endurance (Due to difference in weight)	34 min	18 min

Table 7 Camera Test

Camera try-outs were analyzed keeping in mind the different trade-off such as the weight of camera, resolution of camera, the field of view etc. Both DSLR and mirrorless camera were contemplated for different tests. The team had Sony Alpha A5100 from last year's UAV and Nikon D3300. Both were placed on a test model multicopter used by the development team for various tests and evaluations were made detailed in *table 7.*

After several comparative studies, results and analysis, team chose Sony Alpha A5100 as team was familiar with firmware and for different reasons mentioned in *table 8*.

PARAMETERS	Sony A5100	NIKON D3300	Reason to Select
Image Sensor	24.3MP	24.2MP	Better high true full dynamic resolution of 24.3 MP
Light Sensitivity (Iso)	ISO 100 - 25600	ISO 100-12800,	Better ISO
Battery	400 shots	700 shots	Less Shots but enough for competition
Continuous Shooting	6fps	5fps	Better continuous Shoot
Dimensions	109.6 (W) x 62.8 (H) x 35.7 (D) mm	124 (W) x 98 (H) x 76(D) mm	A5100 size is small and perfect fit in the multicopter frame
Focal Length	16-50mm	35mm	A5100 has Good field of view is achieved with better focal length (16mm)
Price (In INR)	35,000	53,000	Cheaper than D3300
Weight (With Battery)	283 g	672 g	Less weight, reduces payload and increases the efficiency

Table 8 Camera comparison

The imaging system should be capable to control a camera connected to Odroid XU4 via USB, communicate with various sensors through UART or similar protocol. Odroid is connected with Bullet M5 which allow to transfer image to ground station using 5.8 GHz imagery link without the loss of any data. Odroid XU4 is connected to Pixhawk using telemetry 2 port shown in above figure 7 which receive camera trigger signal to trigger the camera. Odroid receives signal from pixhawk and uses pre-stocked algorithm on it to trigger the camera. Team also runs a separate code written in C++ on odroid XU4 to automatically geotag the images during the flight using the signal from GPS connected to Pixhawk

Additionally, images were inspected by team and verified to have sufficient resolution and field of view to resolve the target. It was found at given resolution and FOV (Field of view) as shown below, targets can easily be resolved:

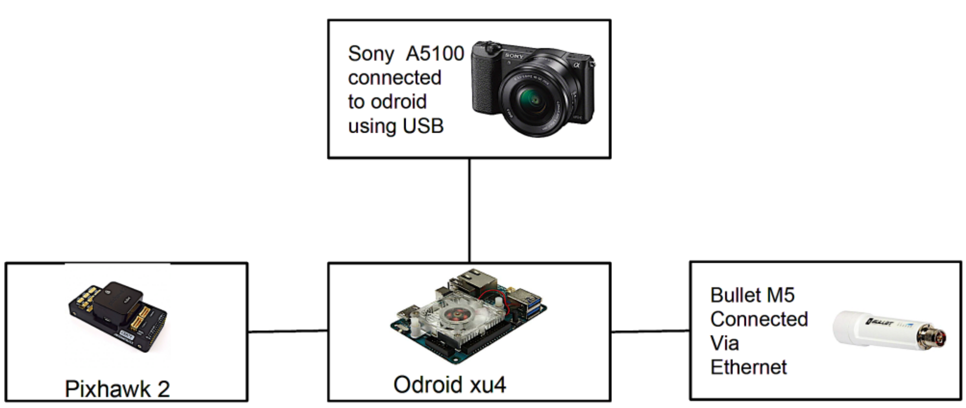


Figure 11 Imaging System

Where,

α = Angle of view,

S1 = Distance between object and lens,

S2 = Distance between sensor and lens,

do = Length of object.

di = Length of sensor, **f** = focal length

$$\alpha = 2\tan^{-1}\frac{d_i}{2S_2} == 2\tan^{-1}\frac{d_o}{2S_1}$$

By setting lens for infinity focus, $S_2 \rightarrow f$

Therefore,

$$d_o = S_1\frac{d_i}{f}$$

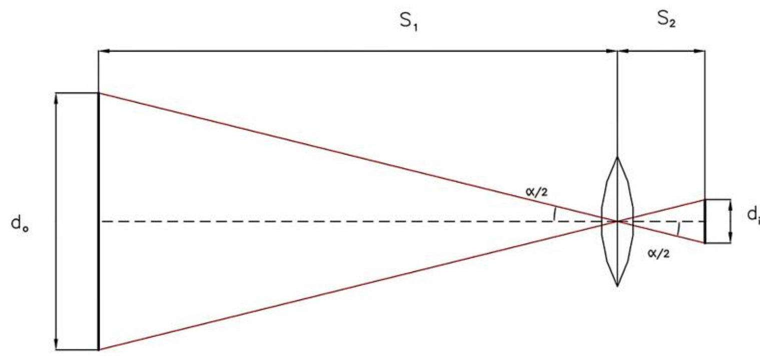


Figure 12 Camera Field Of View

Since, we are using Sony A5100, which has sensor dimensions 23.5(length) x 15.6(breadth) mm. and focal length 16 mm at infinity DPP (Distance Per Pixel) is found as :

DPP$_{\text{Horizontal}}$ **= 0.0238 feet/ Pixel and**

DPP$_{\text{Verical}}$ **= 0.0245 feet/ Pixel**

The results of ground coverage as per DPP provide shows image by camera will be enough to complete ODLC (Object Detection Localization and Classification) for both manual and autonomous.

2.5 OBJECT DETECTION, CLASSIFICATION AND LOCALIZATION

The Ground Stations consist of many computers linked through a network which performs manual ODLC. All stations run custom image analysis software which was built by team this year. The payload operator's computer, which receives the geotagged pictures from the UAV, acts as a server and distributes the pictures to other computers on the network.

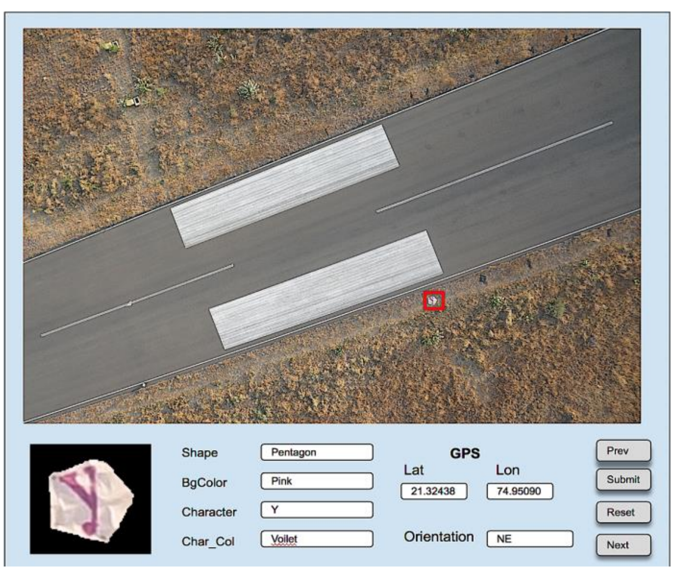


Figure 13 Imagery Console

All Ground operators scan through the incoming pictures and tag targets as they are discovered. 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 change or submit the data obtained or discard it. It also provides feature to manually change the image in case of no target is detected. It is the first time the team has created its own GUI, many tests for the efficiency and optimization were performed on it. It was found that GUI helps in 3 times faster manual detection as compared to last year. GUI also helps us to create JSON file format as per competition requirement which is used by interop operator to submit the data to interop server.

Aerial images captured often have a unique characteristic such that a large portion of images is uniform and uncluttered. The system is able to identify the locations of all such objects of interest in the image before they can be extracted. Team has used following algorithm:

A. Smoothening and Mean Shift Filtering

Gaussian Smoothing is performed on the image to remove unwanted noise. This helps in generating smooth saliency map. Mean shift is performed on the smoothened image which results in a posterized image with colour and fine-grain texture flattened. With appropriate spatial and colour window radius the larger portions of the image that is uniform are clustered together while the smaller objects of interest are still preserved.

B. Constructing Saliency Map:

Saliency map is computed of full resolution, which utilizes colour and luminance information for computing a frequency tuned saliency map. The image obtained after mean shift filtering (I_{msf}) and the image obtained after smoothing (I_{gs}) is converted to LAB colour space. The two images obtained after this step are represented as I_{msf_lab} and I_{gs_lab} for I_{msf} and I_{gs} respectively. Saliency map is generated using arithmetic mean of each channel for all pixels of I_{msf_lab} is calculated using: $\boldsymbol{S(x,y) = |I_{mean} - I_{gs_{lab}}(x,y)|}$

Furthermore, nine different canny edge detection images are calculated. Seven images comprise of images obtained by red, green and blue channel of RGB and two remaining images are canny edge detection on the original image after mean shift filtering (I_{msf}). These nine images are added together to form the final saliency map (S_{final}).

C. Blob Detection

Blob detection is performed on the final saliency map to find bounding boxes of the visually salient regions. To segment, the foreground (visually salient objects in our case) from the image grab cut method is used. The area inside bounding box is marked as foreground while the area outside it is marked as background. The last step for object extraction is to use the alpha-matte calculated in the previous step as a mask on the original image to extract the colored object from the original image.

D. Shape Detection

Ray tracing technique was used to identify the shape of the target based on the corners. This technique was found to be highly reliable and was improved for various distorted shapes with an accuracy of 84%.

E. Color Detection

The color detection algorithm involves the processing of potential targets, composed of two dominant colors—the background color and the alphanumeric character color, with the K-means clustering algorithm. This helps to divide the extracted target into two primary colors value i.e. background colour and character colour. This value is then compared with a predetermined list of HSV values for mapping to the correct name.

F. Alphanumeric

The alphanumeric character is identified using the Tesseract OCR engine. The character with highest confidence level is chosen for the alphanumeric determination.

G. Localization

The image coordinates and orientation are obtained from the image metadata, which along with target distance (in pixel) is sent to localization code which uses Geopy library for the localization and orientation.

The system was built from a series of modules, each module was fed the test images and detected the presence of the object along with the correct color/shape with 80% accuracy. Localization was also improved from previous year. *Table 9* shows few test results for the same.

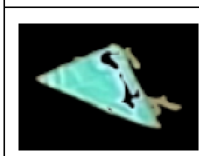
Extracted Target	Localization	Classification	Remarks
	Lat :21.3453 Longitude :76.34528 Orientation: NE	Shape: Circle Colour: Blue Character: A Colour: White	A localization error of 12%. The orientation was found to have an error of 19 %.
	Lat :21.3528 Longitude :76.430530875 Orientation: N	Shape: Pentagon Colour: Pink Character: Y Colour: Violet	All target characteristics were determined correctly.
	Lat :21.4102025 Longitude :76.43052956 Orientation: S	Shape: Triangle Colour: Blue Character: S Colour: Blue	All target characteristics were determined correctly.
	No Geotagged	Shape: Triangle Colour: Blue Character: NA Colour: NA	Incomplete Characteristics due to wrong segmentation.

Table 9 Imagery Data Rates and Signal Strength

2.6 COMMUNICATIONS

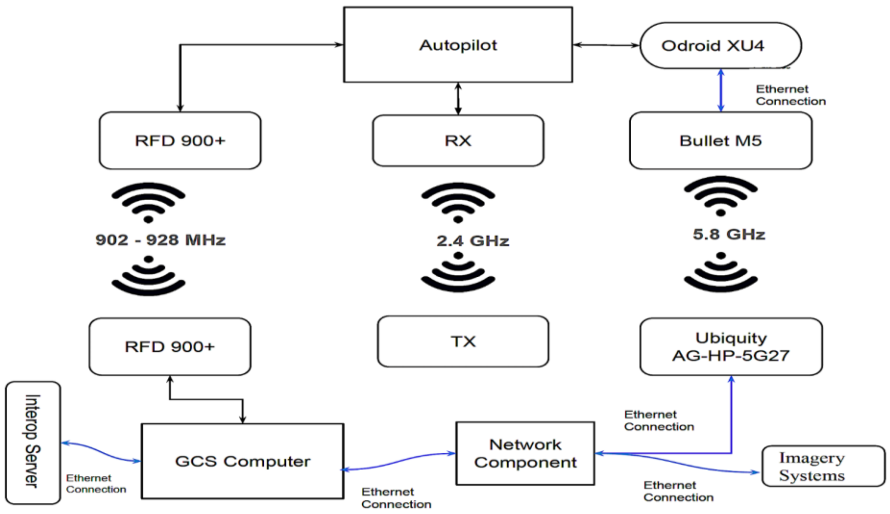


Figure 14 Communication Link

Team has three communication link 2.4 GHz, 900 MHz and 5.8 GHz.

2.4 GHz is used by safety pilot. The pilot uses a Taranis X9D Plus radio controller to communicate with the autopilot using X8R receiver in case of a manual takeover in flight in stabilize mode. It has frequency hopping ACCST technology which takes the advantage of the entire 2.4GHz band resulting in excellent range. Receiver is incorporated with RSSI (receiver signal strength indication) which help to continually monitoring the reception quality to the UAV and alert the pilot if signal goes down below critical level. No test was performed this year as the team has been using the same transmitter and receiver for past two years.

Distance (feet)	Signal Strength (%)
1640	100
3280	98
4100	94
4921	91
6561	87
9843	84
13123	80

Table 10 Telemetry Range Test

Distance (Feet)	AG-HP-5G27		Nanostation M5	
	Signal Strength (%)	Transfer rate (mbps)	Signal Strength (%)	Transfer rate (mbps)
1640	100	94	92	90
3280	98	89	84	81
4100	94	81	75	68
4921	91	77	68	59
6561	87	69	59	46
9843	84	51	49	38

Table 11 Imagery Data Rates and Signal Strength

RFD900+, operating on the 900 MHz band, are used to provide telemetry data between the ground station and the hexacopter. It uses the 902 – 928 MHz band. Ground test with line of sight was done to check the performance of the telemetry link *(table 10)*. Performance was adequate and one of the major benefit of using RFD is that communication is encrypted.

Team uses 5.8 GHz frequency for the Imagery communication system. Team uses Ubiquity Bullet M5 and Ubiquity AG-HP-5G27 for the communication. Bullet M5 is connected to OBC (On Board Computer), Odroid XU4, which maintain real-time images transfer to the ground analysis station. Team has tested using a Bullet-M5 first and Nano station M5 connection but was unable to get required signal strength along with transfer rate. Range tests were also performed over a large distance using Nanostation M5 and AG-HP-5G27, with the results presented in *table 11* showing that Airgrid antenna has better strength and transfer rate

2.7 AIR DELIVERY

The Airdrop Mechanism secures the water bottle to the hexacopter and allows a quick and precise drop. Airdrop mechanism consists of mould case made up of nylon plastic. It consists two 9g Servo to open the twin doors. Airdrop case is located outside the vehicle for easy access. The system is not only lightweight but also easily detachable from the vehicle. Team has also attached a safety switch using a servo which is controlled by safety pilot to protect the bottle from an accidental drop.

Figure 15 Airdrop Mechanism with safety Servo

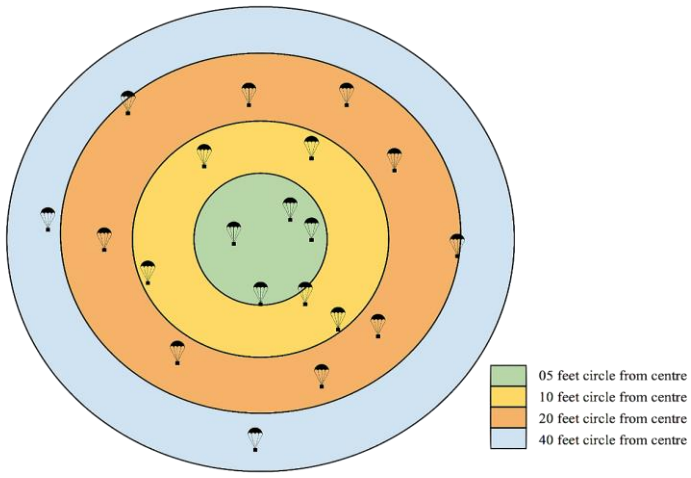


Figure 16 Airdrop

Unlike fixed-wing aircraft, we are able to achieve a velocity of 0 m/s when attempting the air delivery task. This gives an advantage over fixed wing aircraft for precise and accurate air drop.

Following freefall, the water bottle breaks on impact and water is dispersed on the point of impact. Airdrop mechanism was tested on a concrete floor. Due to hover capability of the hexacopter, the precision of the drop varied between four and twenty feet. From test results, we found that the best airdrop achieved was 4 feet from center and the worst 28 ft from center. The *figure 16* shows results of drop test around the desired location.

2.8 CYBER SECURITY

The team takes a comprehensive approach to ensure that the system is protected by cyber-attacks whenever possible. Table 12 shows possible cyber security attack, mitigation and test result.

Component	Risk	Mitigation	Test / Test Result
Imagery Link (Wifi)	Hacking	Team has password protected using WPA2 security with minimum 32 character	Dictionary attack and brute force was performed but it was unable to crack the password.
Imagery Link (Wifi)	Jamming	Imagery link works on 5.8 GHz and is rarely used, so there is less chance of interference. In worst situation images are store in Odroid and can be accessed later	No Test
Imagery Link (Wifi)	De-Authenticate Attack	Team creates a hidden network (SSID Hidden) to overcome this attack. A hidden Network can't be found by attackers	De-authenticate Attack was carried out using Pentesting OS but was unable to de-authenticate as network was hidden
GPS - Here (M8N)	Spoofing	Here GPS receivers offer spoofing detection, which can alert the plane and tell it enter failsafe mode (RTL or Loiter). Safety Pilot take control and land	Ground test was done to spoof GPS using HackRF, found that Autopilot enters in safe mode
Compass of GPS	Jamming	Proper failsafe is designed to prevent jamming in case of Interference	No Test, as it's practically not feasible to create interference and too risky
RC Link	Hijacking	The GCS can override the pilot’s commands in case of problems and perform various actions depending on the situation	Team has manually switched off the RC to simulate the same situation & found that gcs was able to perform appropriate actions.
RC Link	Jamming	GCS can override and failsafe is defined for such situations	Physical check on the ground was done to simulate the same. autopilot goes to RTL.
Telemetry link	Hijacking	Team uses RFD 900+ which uses encryption for communication as well as default ID is being changed.	RFD with same Net ID was tested and found that cross connection is possible in case of same Net ID
Physical Security	Human Error	All the memory and database are encrypted and can be only be accessed by single user i.e. team captain. This minimize the human error.	No Test
Router	Default Setting	Default Setting and password was changed. Latest firmware was installed to overcome any exploit.	Default username and password was tested to check if system is exposed to security

Table 12 Cyber Security

3. SAFETY, RISKS AND MITIGATION

Safety is an essential factor that has to be considered in order to deploy a fully functional autonomous flight. Continuous risk assessments were carried out throughout the process of developing and flying in order to minimize the harm of personnel and property. Keeping safety aspect of the mission as the first priority, Team UAS NMIMS created mitigation methods taking into account all the risks. As a result of these mitigation plans, team achieved maximum safety during the development and testing process. This section explains the mitigation methods created by the team in detail. The risks and their mitigation strategies are divided into two categories- Developmental risks and Mission risks.

3.1 DEVELOPMENTAL RISKS AND MITIGATION

Risk	Likelihood	Severity	Mitigation Strategy
Design and/or manufacturing delays	Low	High	Design and Manufacturing of modification part was started very early after mission requirement analysis which minimized the delays. Extra parts were ordered to minimize time delay. Additionally, weekly meeting was conducted to review the design and changes.
Integration issues	Medium	High	The development team was divided in sub-teams. A sub-team leader was assigned who had a thorough understanding of the system to ensure that all the necessary requirements were fulfilled before integration into the whole system.
Injury due to bad usage of tools	Low	Medium	User Manual of the tools were read by the team and was kept handy while using the tools. First Aid box was used to minimize the risk in case of emergency.
Exposure to toxic chemicals	Low	Low	Use of proper safety equipment like sunscreen, gloves, sunglasses etc.
Insufficient personnel training due to entry of New Member	Low	Medium	New personnel worked under the guidance of senior members who were well-trained.
Electrical malfunction/ damage	Low	High	Read each component’s documentation to ensure the correct voltage was supplied. Followed a circuit diagram for installation. Ensured all wires were properly insulated
Improper tuning of Hexacopter	Medium	High	An experienced safety pilot tuned the hexacopter, verification of tuning was done by multiple test flights.

Table 13 Development Risk and Mitigation

3.2 MISSION RISKS AND MITIGATION

	Risk	Likelihood	Severity	Mitigation Strategy
COMPETITION MISSION	Unexpected aircraft behavior	Low	High	Autonomous paths are validated before being sent to the UAV and can be overridden at any time by the GCS operator or pilot
	Unauthorized air delivery	Low	Low	Manual Safety switch is incorporated which is under control of pilot for unauthorized air delivery
	Failing to meet the mission time limits	Low	High	If the mission time limit is about to be reached, cancel all leftover mission objectives land immediately
	Loss of RC link to the UAS	Medium	High	Pre-flight tests are performed and autopilot fail-safes was properly designed and checked

AUTONOMOUS FLIGHT	Loss of control over the plane	Low	High	Manual control by safety pilot and in case of loss in RC link, GCS operator to override the operation
	Crash during autonomous mission practice	Medium	High	Backup aircraft was made in case of any crash to minimize the effect.
	Breach of competition's rules	Low	High	A thorough inspection of the rules and regulations were made before airframe design and team noted all the rules.
	Damage to LiPo batteries	Medium	Medium	Transportation in Li-Po safe bags. Proper care was taken while charging and discharging the batteries
TESTING	Mistake from the pilot	Low	Medium	Spotter was assigned for this purpose, autopilot override to be executed immediately.
	Incomplete plane preparation	Medium	High	Pre-flight tests and validation, including hardware, center of mass verification, control surfaces. Connection to propeller and motor is also to be checked twice.
	Injury from propeller	Medium	High	Anyone having contact with the plane during setup wears gloves and safety glasses. Checklist manager verifies mitigation compliance. Safety switch is also incorporated to overcome accidental spinning.
	Human Error	Low	High	Test Fight Safety Manual, pre-flight checklist and training to team members.

Table 14 Mission Risks and Mitigation

CONCLUSION

Complete deployment of *Black Peafowl* was full of challenge. The team tackled the intricacies at all times successfully and made a safe and mission friendly autonomous aircraft. The UAV thus made is capable of performing different missions and tasks both manually and autonomously with the help of different electronics in various subsystem complementing each other.

This year a new frame was chosen by the team and its modification and testing were done to improvise aerodynamics, software, interoperability and image system. As hexacopter was a new concept for the team, different studies and tests were done on UAV's aerodynamics, airframe and components for ideal results. Also a new algorithm was prepared for camera triggering. Extensive flights and mission testing confirms flight readiness of team UAS NMIMS for 16th AUVSI SUAS competition