Inter IIT Tech Meet 8.0
Mid Evaluation Report - IIT Madras

# D.R.D.O. SASE's UAV Fleet Challenge

## Introduction

A modern search and rescue scenario poses various challenges for the teams undertaking the search and rescue operation. The primary goals for these teams are the fast exploration of the disaster area and the fast rescue of the victims. In many cases the searching procedure endangers the search team members, which may be the case in unstable buildings after an earthquake or in the wake of a nuclear disaster. Also in many scenarios the search area might be difficult to access directly by the team members such as in the case of hillaneous regions and floody areas. This naturally leads to the introduction of robots in these kinds of scenarios.

Miniature aerial vehicles are ideal candidates for such missions as they can use three dimensional maneuvers to overcome obstacles that cannot be overcome by ground vehicles.using a swarm or a fleet of robots naturally follows in order to make efficient use of human resources and save time . However, significant technological challenges exist in order to ensure reliable operation in such environments . Factors such as path planning and coordination among the multiple vehicles directly affect the overall performance and effectiveness of the search operation . communication speed and latency directly affect feasibility and scalability.

Finally, the UAVs should be designed to be expendable due to the dangerous environments it needs to operate in, hence low-cost, low-weight designs need to be explored. These restrictions pose significant technological challenges for the reliable design of a fleet of autonomous UAVs for a Search and Rescue Operation

## Conceptual Solution

Our approach to solve the given Problem Statement involved splitting the problem into various sub-modules or sub-problems and tackling each individually. Once a reasonable working model of each sub-module is obtained, they will be integrated into the final system. The sub-problems or sub-modules consist of:

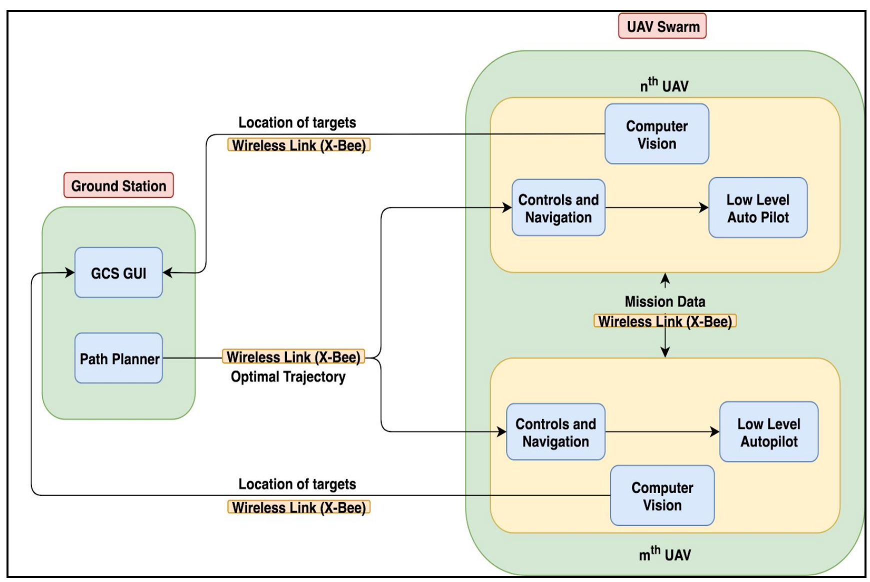



**Fig.1 System Overview**

- **Hardware Design : -** Multirotor propulsive drive optimisation followed by fabrication and assembly of the airframe succeeded by tuning and testing of the flight performance. The combination of the fine-tuned parameters and the optimised drive will result in a better flight performance.
- **Exploration Algorithm / Path Planning : -** The exploration (path planning) algorithm required by the fleet to coordinate and search for the predefined target using available resources and information efficiently, minimizing the time required.
- **Communication : -** Design of the network architecture and the hardware framework for enabling wireless communication within the swarm and also connecting the swarm and the Ground Control Station (GCS).
- **Controls and Navigation : -** Design of the high level navigation/guidance controller for executing the High-level setpoint commands generated by the path planner. This module then generates low-level setpoints for the autopilot to execute.
- **Computer Vision: -** Detection and geolocation of the predefined target characteristic representative.

# 1. Hardware Design

Some of the popular Multirotor airframe layouts available for commercial applications are : Quad,Hexa and Octa. (Quad: 4 motors and so on..).There are other airframe configurations available but these are widely used due to their mechanical simplicity and efficiency. Out of these we have selected Quad layout for our drones as we dont need a very high payload capacity and also we need a scalable cost-efficient solution .

| Quadcopter | Hexacopter | Octacopter |
|---|---|---|
| Cheap | More Expensive | Costliest |
| Maneuverable | Less Maneuverable | Relatively Less Maneuverable |
| No motor failure redundancy | Single motor failure redundancy | ultiple motor failure redundanc |
| Limited payload | Relatively higher payload | Higher Payload |

Once the airframe layout is selected we need to finalise the drive components best suited for carrying the specified load weight for the required endurance period. This is an iterative procedure which involves initial weight estimates of all the components and mathematical models for evaluating the performance of the chosen drive components.

This paper[1] was used for developing the mathematical models for performance evaluation. We execute a slightly different approach for selecting drive components.Once the models are ready, we use the models to solve a inverse-design challenge[2] to find the parameter values of different components that are best suited for the demanded requirements.

Based on our choice of components the estimated **AUW (All-up-weight) is 1.5Kgs and Endurance is 10+ minutes**.

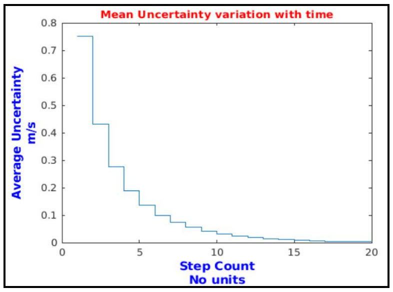
## B.O.M :

| Component | Name | Cost (INR) |
|---|---|---|
| Airframe | S500 Quadcopter frame kit | 1750 |
| Motors | Avionic MT3506 850KV | 1250 |
| Propellers | Gemfan 12"X5" Slow Flyer | 550 |
| ESC | Hobbywing SimonK 30A | 1250 |
| Battery | Orange 3000mAh 3S 30C | 2850 |
| On Board Computer | Raspberry Pi 4 (4GB variant) | 4750 |
| Communication Transceiver | Xbee Pro XSC S3B 900Mhz | 3000 |
| Flight Controller + GPS | Pixhawk Kit + Ublox NeoM8N | 8000 |
| Camera | RPi Cam V2 | 2250 |
| **TOTAL** | | **INR 25,650** |

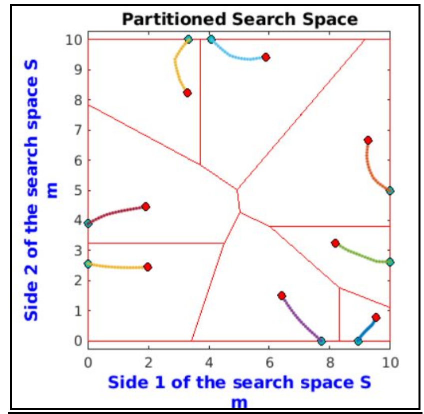
**[1] X. Dai, Q. Quan, J. Ren, and K.-Y. Cai, "An Analytical Design Optimization Method for Electric Propulsion Systems of Multicopter UAVs with Desired Hovering Endurance," IEEE/ASME Transactions on Mechatronics, vol. 24, no. 1, pp. 228–239, 2019.**

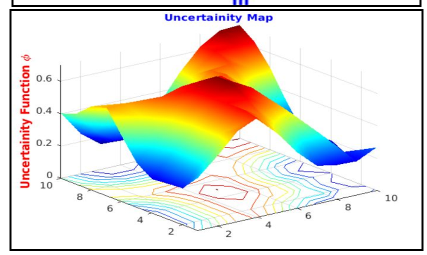
**[2] X. Dai, Q. Quan, J. Ren, and K.-Y. Cai, "Efficiency Optimization and Component Selection for Propulsion Systems of Electric Multicopters. IEEE Transactions on Industrial Electronics, vol. 66, no. 10, pp. 7800–7809, 2019**

## 2. Exploration Algorithm / Path Planning




The exploration algorithm we have decided to implement is based upon **Centroidal Voronoi Tessellations** and is referenced from the following paper [3]. This is a probabilistic approach in which we assume an initial uncertainty distribution about the environment (e.g a uniform distribution if the object is equally likely to be present anywhere). The uncertainty is then reduced by exploring the environment and collecting information about it using sensors (eg. in our case RGB Cameras).




The agents are deployed in an **optimal way** so as to **maximize the one step uncertainty reduction** i.e move in an optimal way to maximize the probability of finding the target . Preliminary simulations were carried out in matlab and the algorithm was verified. The final implementation for the actual fleet is still in progress.

Few advantages the aforementioned algorithm to other traditional approaches like sweep line search etc

- The algorithm is **Optimal** i.e The various UAVs deploy themselves in a manner to find targets in the fastest possible time
- The aforementioned algorithm is **dynamic** and hence is adaptive to unforeseen circumstances (a UAV failing in between) and doesn't lose out on it's optimality
- This Algorithm is **readily scalable** with respect to hardware and software requirements. The drones only require information from its neighbours to negotiate and calculate its next action

## 3. Communications

In the effort to construct a robust communication system that ensures efficient completion of tasks and dynamic scalability of the number of drones, we were faced with the following challenges.

Hardware challenges:The trade-off we were faced with is that of range vs latency. Although traditional methods like WiFi or Bluetooth come with a relatively low latency they are limited by the range they provide.In the real world applications (for example in the case of detecting survivors in an avalanche) where drones may need to communicate over several km amongst themselves or with the ground station, the Xbee S3B Pro module comes in handy.

A few key features of the Xbee S3B Pro module:

- Latency **< 100 ms** and range **> 45 km** with high gain antennas.
- Uses the Sub-Ghz Unlicensed Band ( **900 Mhz** ) for communication and hence can be scaled up easily without facing any regulations issues.
- Virtually no interference with popular Wireless Solutions such as WiFi or RF communications used in Drones as they use the **2.4 / 5 Ghz** band.
- Availability of further network parameters which can be configured to minimize interference between multiple sets of devices operating in the same vicinity.
- Power consumption of **< 1 W** thereby having a negligible effect on the flight time of the UAV.

[3] **Guruprasad K. R. and Debasish Ghose "Multi-agent search strategy based on centroidal Voronoi configuration" , 2010 IEEE International Conference on Robotics and Automation**

- Other features:
- Centralised (Ground station based) approach:
  - A centralised drone leader based approach is prone to network failure due to an unbalanced command distribution and control prioritisation.
  - A ground station network is more reliable in the case that a node (drone) breaks down.
  - Therefore we have chosen a centralised ground station network well equipped with handling the loss of a drone for our application.
- Implementation of both broadcast and unicast modes of communication with time synchronized transmission of data for accurate Voronoi partition calculations.

## 4. Controls and Navigation

The exploration algorithm running from the ground station generates optimal trajectories for the maximum likelihood of Target Identification .The guidance of these multiple UAVs for tracking the generated paths is accomplished with the help of **ROS and the ArduPilot Flight Stack**.

We use ArduPilot ( an Open Source autopilot for Multirotors ) for the low level control and stabilization of the Aerial vehicle. We have chosen ardupilot for its **extensive list of features and reliability**. The open source API is very user friendly and can easily be coupled with ROS to develop UAVs for custom applications

ROS is a very popular open source Robotics framework which is used in the rapid development and prototyping of Robotic Systems .MAVROS is a ROS package which enables MAVLink communication between computers running ROS, MAVLink enabled autopilots (Ardupilot), and MAVLink enabled GCS. An onboard computer running ROS and MAVROS is used to generate low level setpoints from the high level setpoints received from the exploration algorithm for the flight autopilot enabling autonomous flight.

Furthermore integration with Gazebo simulator enables us to test our codes without risking damage to property and life. This entire software framework enables us to **rapidly develop, test and modify the programs**.

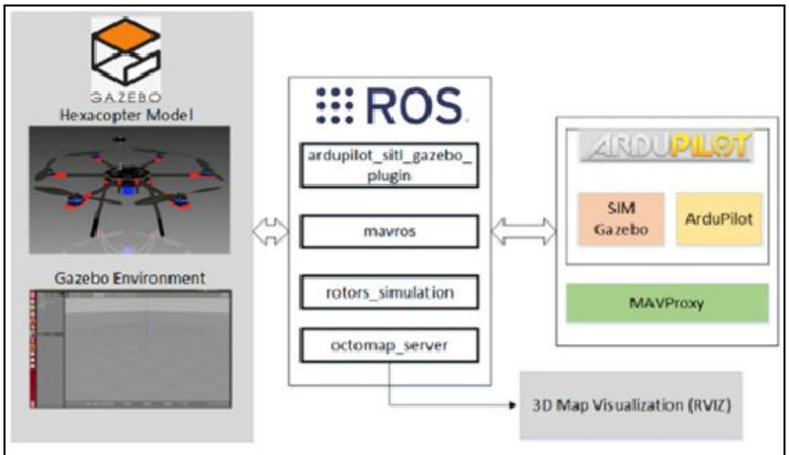
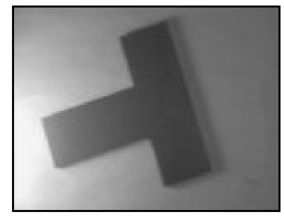



Figure 1. Architecture System of Simulation

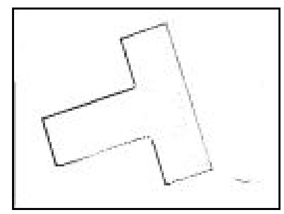
## 5. Computer Vision

A **conventional CV approach** (no DL) was opted as a lot of data is needed for a DL based approach. Also a **DL based approach would require more computation power** hence increasing the computation time and would also require additional hardware for optimal operation, thereby slowing down the entire pipeline.

We are **using adaptive thresholding** as our edge detection method, as in simple thresholding, the threshold value is global, i.e. it is the same for all the pixels in the image. **Adaptive thresholding is the method where the threshold value is calculated for smaller regions** and therefore, there will be different threshold values for different regions, **hence it is much more dynamic than other approaches**.



We have also used **morphological opening and closing** to get rid of noise in the adaptive thresholding output instead of other methods like FastNLDenoising for speed.



On the detected edges we've drawn contours, and we have approximated polygons around each of these contours and then we have taken square like ones from these, giving a margin of **flexibility on dimensions and its aspect ratio**. These parameters can hence be **changed very easily to detect any other objects** of different shapes and dimensions.

On these square contours we've checked if the color lies in the green range on HSV using a base H value and a **sensitivity parameter to extend the range of detections** on the green spectrum.

We are also implementing an algorithm to approximate the GPS location of the box in any part of the frame. This algorithm uses distance scaling and oblique correction to obtain good estimates of the GPS location of the target.

**Advantages of our approach are** :-

1) **Lighter and computationally cheaper** than a DL approach
2) **Faster and more dynamic** than other traditional CV methods
3) **Higher Accuracy** due to Dual feature approach
4) Requires **minimal hardware** like an RPi ( DL would require a more expensive processing unit) and only a cheap camera to operate (an RPi v2 camera).