D.R.D.O. SASE's UAV Fleet Challenge: Mid Term Report
IIT Bombay

Introduction: We intend to develop a swarm of four quadrotors to search and locate the object over the target area. Our team has been divided into three subsystems:
(i) **Hardware**: Team of two to design and manufacture the quadrotors.
(ii)**Software - Flight Control & Communication**: Team of four to identify and implement algorithms to enable stable flight of each of the agent of the swarm. The team will also be working towards implementing algorithms for locating objects. Additionally, the team will oversee the communication necessary among the swarms as well as between the ground station and swarm.
(iii)**Software - Object Identification and Mapping**: Team of two to study and implement algorithms to identify and map the coordinates of relevant objects in the target area.

In the subsequent sections, we have described our plan of action. Each of the team explains in detail the work that has been achieved so far.

Plan of action: An extensive literature survey on the use of UAVs for area coverage, surveillance was carried out by our team. We decided to work with a fleet of four quadrotors since more number of quadrotors ensure time optimality. Moreover, quadrotors were a clear choice of the type of UAV owing to their high maneuverability compared to fixed-wing aircraft. Each of the quadrotors will use a Pixhawk loaded with PX4 firmware as the flight control unit as well as a Raspberry Pi that will run the necessary search and object detection algorithms. We intend to use a zigbee to broadcast and transmit data among the agents and the ground control station. The ground-station will be an off-board computer running Robot Operating System (ROS). The fleet will start at a fixed point and each of the individual agents will autonomously allocate themselves a quadrant of the target area. Each of the quadrotors will then implement a search strategy while covering their allocated areas to locate the objects of interest. The locations of each object will be broadcast to each of the other agents in the swarm as well as to the ground-station. For safety/manual maneuvers, we intend to use ROS to control UAVs using a joystick. For Object detection, we intend to use openCV for image processing and if needed, tensorflow, for machine learning.

Hardware
The nature of the problem statement demands quadrotors with sufficient flight time and payload carrying capacity. The quadcopters should remain unaffected by gusts of wind as we would be implementing image processing. This would remain one of the significant factors in the accuracy of image processing. Based on these constraints, the following materials were carefully chosen:
Frame: The frame should have sufficient space available onboard to mount the camera and Raspberry Pi module. While a frame size of 450-500mm would have been sufficient, we had to choose a 580mm frame because of the limited availability of frames in Indian markets. One of the necessary features we required was a landing gear since our camera would be mounted at the base. The frame comes with a gimbal suspension bar which would facilitate the camera mounting for image processing.
Motors: From the data[1] available for the frame, we chose Avionic 3506 [580 kv].A lower Kv rating implies higher torque and could be used for a longer duration of flights. Based on our weight estimate [2000 grams], we required a thrust to weight ratio of around 2. With the recommended propeller combination and 4S battery, the motors generate the required thrust, as shown in the given calculations[1], done on *Ecalc.*
ESCs: Selection of the Electronic Speed Controller (ESC) is based on the current and voltage rating of the motor. The current rating of the ESC should be more than the current rating of the motor. Voltage rating of the ESC should be same as that of the motor.
Based on these considerations and taking availability factors into account, we selected the EMAX and Littlebee 30 A ESCs.
Propellers: From the datasheet[2] for Avionic motors, we concluded that 1345 propellers [Diameter= 13 inches, pitch=4.5 inches], coupled with a 4S battery would generate the required thrust and flight

time. Although we have been trying to find 13-inch propellers in India, if we fail to do so, we would go with 1245 propellers.
Power Distribution Board: The only special requirement for a PDB was a voltage regulator, which could be used to power up Raspberry Pi and the camera module. A Matek XT60 PDB with 5V & 12V BEC was chosen accordingly. It is compatible with 3S-4S Lipo battery.
Flight Controller: Achieving autonomy could be done with either Pixhawk 2.4.8 or Navio 2. We concluded that Navio was relatively expensive and almost all the operations that Navio could perform could be done on Pixhawk 2.4.8 with a companion computer. It is a full autopilot capable of autonomous stabilization, way-point based navigation and support for two way telemetry with radio telemetry modules.
Battery: With the on-board processing and a minimum required flight time of over 10 minutes, we had to select a 5200 mAh 4-Cell Battery. Raspberry Pi 4 Model B requires 5V 3A output.
Raspberry Pi 4 Model B: Companion computer which links with Pixhawk to establish MAVROS.
Camera: The main reason behind the selection of this camera is the fact that this camera is digital and can be operated directly by OpenCV. The other choice was an FPV camera but the issues with FPV camera was that it cannot be operated directly by OpenCV which is our choice of image processing library. Apart from the camera weighs around 200g which is compatible with the drone's payload capacity

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The Complete list of parts to be used along with their price is linked below:
https://docs.google.com/spreadsheets/d/1N6VCp2U4N6Bu5RVCum625yDPrBqwYPPsQAHEpUTNQUA/edit#gid=0
[1]Calculations for Hover Flight time, Thrust to weight, specific thrust, Electric Power consumed:
https://docs.google.com/document/d/11BRITNr7fXRhoFBoohQz38YsXLld990DmMNDcUEJW_E/edit
[2]Datasheet for Propeller-Battery combination for the motors:
https://docs.google.com/document/d/17DkgvdCc3e5Hj3PayQbwUc2dAc7dHc01QSi3b68LZy8/edit?usp=sharing
Weight Estimate for the quadcopter
https://docs.google.com/spreadsheets/d/1Y-YGJIjOnDfWwUl1xdqJwBwtUeaT5Iatt02cdn7xYfM/edit?usp=sharing

Progress Report: Software - Flight Control and Communication

Flying Multiple Agents: Recent research has shown the potential of Robot Operating System (ROS) to fly a swarm of robots[1][2]. Prof. Ayanian's work has been demonstrated on nano-quadrotors called Crazyswarm. We are using work as a guide to fly multiple robots using ROS. Since, our own quadrotors are not yet ready, we are trying to use two standard quadrotors available to us to test the aforementioned strategy.
Area Coverage Algorithm: Surveys on UAV coverage algorithms[3][4] compare several strategies for UAV coverage and target searching. Acevedo et. al. have presented a decentralized approach to partition the target area into subregions and subsequently use one-to-one coordination for technique for data sharing among the agents. Such a decentralized approach helps in optimization of time required to search the target area. It significantly reduces the probability of missing any target. Moreover, it also reduces computational complexity since it reduces the communication load on

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[1] "Flying Multiple UAVs Using ROS - USC ACT Lab - University ...." https://act.usc.edu/publications/Hoenig_Springer_ROS2017.pdf. Accessed 28 Nov. 2019.
[2] "Crazyswarm: A large nano-quadcopter swarm - IEEE Xplore." http://ieeexplore.ieee.org/abstract/document/7989376/. Accessed 28 Nov. 2019.
[3] "Survey on Coverage Path Planning with Unmanned Aerial ...." https://www.mdpi.com/2504-446X/3/1/4. Accessed 28 Nov. 2019.
[4] "The coverage problem in UAV network: A survey - IEEE Xplore." https://ieeexplore.ieee.org/document/6963085/. Accessed 28 Nov. 2019.

individual agents. We intend to use this strategy for allocating the area and data transmission among agents.

Path Planning: After the decomposition of the target area into subregions, the path planning in these individual subregions needs to be addressed. Several strategies[5] have been proposed in literature to ensure time optimal coverage of area. Some of the most commonly used techniques include: Spiral Technique, Spiral-like Technique and the Lawnmower technique. Studies have concluded the spiral technique to be efficient for a single sweep flight plan. Since, we are expected to achieve the task in minimum time, we aim to avoid repeated sweeps. Hence, the spiral technique is best suited for our application. However, if on practical implementation we find the technique to be underperforming when locating objects, we intend to resort to the lawnmower technique.

Hence, our finalized strategy can be listed down as follows:

(i) The agents identify the target area marked by white borders over the green surface.

(ii) The agents then autonomously assign a subregion(quadrant) for searching objects.

(iii) Each of the agent then flies a clockwise spiral path inwards from the boundary.

(iv) Whenever an object is detected by an agent, the location of the object is transmitted by the agent to the ground control unit as well to a specific agent in its neighbourhood. The data propagates among agents by one-to-one coordination between an agent and it's pre-programmed mate.

(v) As a contingency, if the agent does not detect any object in its subregion, it sweeps the area once again before returning home.

(vi) The objects located are stitched onto a single map(i.e. mapped with reference to a single origin) on the ground control station.

Since our own quadrotors are not yet ready, we are using two quadrotors available to us to implement and test the strategies. We are still in the process of readying the two quadrotors for the purpose of these tests. We first intend to fly these two drones using a joystick and ROS. Then we intend to test the adherence of agents to a pre-programmed flight path. The next step would be to program and test our entire strategy. Over subsequent iterations, we intend to extend this strategy to four drones and then port them to the quadrotors that we intent to make.

<u>**Progress Report: Software - Mapping**</u>

Once the object is detected in an image ,then the following described method will be used to find the coordinates of the image with respect to position of the drone at the moment the image was taken. After the location of the object has been found with respect to drone, the coordinates of the drone at the point of time when the image was taken will be used to map the object in the global map.It is assumed that the position of the drone in the image is at its center. After the object is detected we can find the center of the object in the image w.r.t. center of the image. This will give us the distance between the center of the image and center of object in terms of pixels which will then be converted to S.I.units. The conversion will be achieved by simply calibrating the camera against the real length and breadth of area covered in single image.

<u>**Progress report: Object Identification and Image Processing**</u>

The task of this sub-system will be to develop an algorithm that will be used to identify the presence of an object from the images captured from the drone and then map the objects.

ALGORITHMS

A survey of literature was carried out. Currently the plan is to avoid Deep Learning algorithms as there is a lack of processing power onboard. Although if the Classical Techniques fail to meet the standards then the team will shift its approach towards algorithms involving Deep Learning. Currently an algorithm in classical domain is being developed which uses thresholding to identify the object, but the number of false detections are quite high, as it also identifies some regions of background as object. In

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[5] "Multiple UAV area decomposition and coverage - IEEE Xplore." https://ieeexplore.ieee.org/document/6595424. Accessed 28 Nov. 2019.

order to overcome this a classifier is being implemented which can tell the difference between background and object. Although this algorithm is just an elementary idea and shall be developed upon further or completely discarded if the team manages to come forth with a better and more efficient algorithm.
Here are some of the results the team was able to produce with the above mentioned algorithm. This algorithm was. The following images will clearly show that as we increase the background noise then the number of false predictions increase at an alarming rate.

TEAM MEMBERS:

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