Super Squadron technical paper for

International Aerial Robotics Competition

C.Aasish (M.Tech Avionics)

Cyril Anthony

Team Reconnaissance

ABSTRACT

The Team Recon from India present an indigenously developed Super Squadron an autonomous quad copter designed for the 7th mission of the AUVSI International Aerial Robotics Competition (IARC).This paper describes the technical details of a quad rotor system to be used as an aerial robot for interaction with ground robots and demonstrate the mission requirements. The Super Squadron exhibits the required behaviours of autonomous flight for interaction with multiple objects on ground to recognize, track and navigate in a sterile environment with no external navigational aids. The objective of multiple object tracking would be achieved using HOG- based SVM. The algorithm runs on an ARM Processor with depth camera and the autonomous navigation is done by using optical flow with higher resolution. The instant sensing by aerial robots and interaction between aerial and ground robots would be achieved - by depth sensor and a custom developed ANN and through the use of effective path based algorithms.

I. INTRODUCTION

Mission 7 of IARC conducted by AUVSI provides a challenging opportunity - as a technology sport - to create significant and useful mission challenges in aerial robotics behaviour for the benefit of world. Present challenge involves demonstration of three new behaviours viz., interaction between aerial robots and autonomous ground objects, navigation in a sterile environment (with no external navigation aids) and interaction between competing autonomous air vehicles. The project requires demonstrating capability to track randomly moving objects and interact physically with them.

Team Recon from India present an indigenously developed Super Squadron an autonomous quad copter to be used as an aerial robot for further interaction with ground robots and demonstrate the mission requirements. The Super Squadron exhibits the required behaviours of autonomous flight, tracking of randomly moving objects and interacts physically with objects.

A. Statement of the problem

The main objective of the 7th mission of IARC requires an aerial robot that can demonstrate three new behaviours viz., interaction between aerial robots and autonomous ground objects, navigation in a sterile environment (with no external navigation aids) and interaction between competing autonomous air vehicles. The project requires demonstrating capability to track randomly moving objects and interact physically with them.

B. Conceptual approach

Team Recon has developed a multirotor capable of exploring unknown environment and implementing specific operation without any external navigation aids such as GPS. An integrated vision based navigation method is adopted to provide attitude, altitude, velocity and relative position estimation of the quadcopter within the indoor environments. Multiple objects are detected by HOG-based SVM running on an ARM processor. Safety is a primary concern, so we have installed the kill switch that does not depend on the On-board computer and works independently. In order to protect the direct collision with obstacles, the propellers are shielded.

The overall structure of the aerial robot is custom designed and we have fabricated it using carbon fiber and 3-D printed parts. The aerial robot is installed with tall landing skids in order to interact with the ground robots. The aerial robot is also equipped with LIDAR and ultrasonic sensors which are primarily responsible for avoiding the obstacles. The autonomous aerial robot following a vision based navigation method thus guides the ground robots towards the green line and dodging the collisions and making the mission successful.

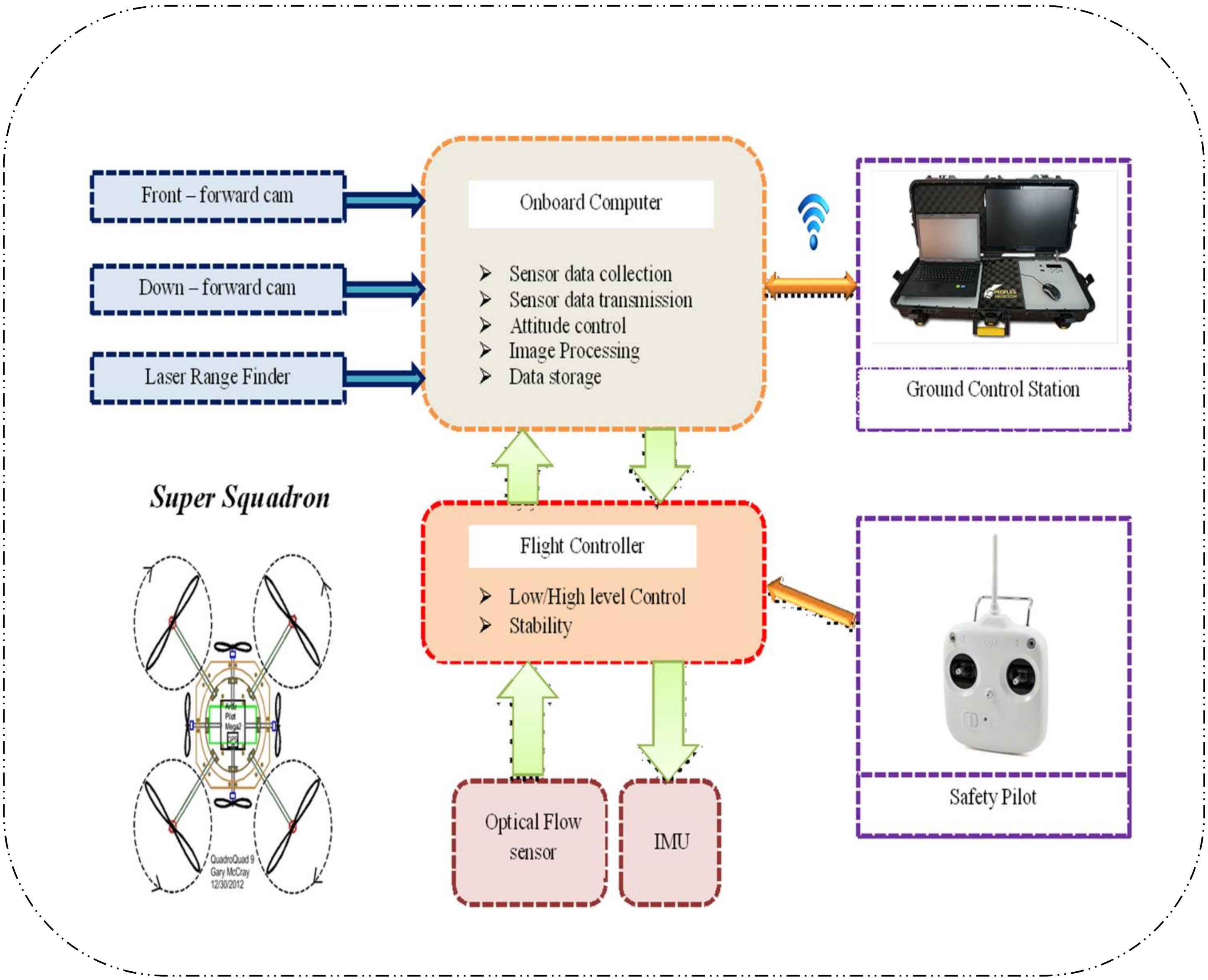


Figure1. Overall system Architecture

C. Yearly milestones

This is the third time for the team Recon to participate in IARC's mission 7. The last year's participation gave us some good experience and knowledge about the advanced technologies used and so we are rectifying the error of unstable algorithm .Through the experience and knowledge gained we are developing Super Squadron for this year's mission and our progress is steady.

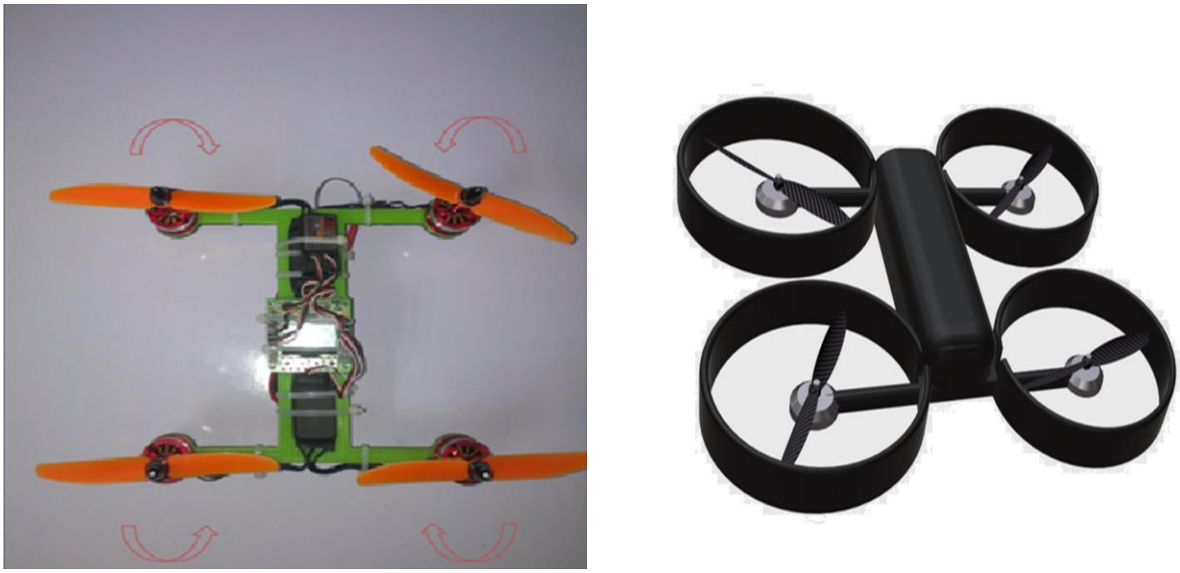
II. Air Vehicle

We chose quadrotor helicopter as the flight platform for the mission as it is a mechanically simple vehicle, requiring only four motors to achieve all flight motions. The quadrotors are an ideal choice for accomplishing the mission as they have high manoeuvrability and the ability to fly in challenging environments. The quadrotor airframe is a custom-designed structure and has been fabricated using carbon fibre, glass fibre and plastic. The endurance of the UAV varies between 32 minutes and 18 minutes without and with full payloads respectively. It carries a payload of 500 grams. The thrust of the UAV is generated by varying the RPM (rotations per minute) of the motors. The RPM of the motors are regulated using a built in controller. The built in controller consisting of the Inertial Measurement Unit (IMU) is primarily responsible for maintaining the flight characteristics in the optimum level. The IMU consists of accelerometers and gyros provide reports about the acceleration and orientation of the UAV. The telemetry data of the copter is viewed on the laptop and the data is transferred using 2.4 GHz transceivers. The flying vehicle consists of two on-board cameras and computations are done off-board on an i5 laptop. The on-board camera data is streamed via Wi-Fi. With the installation magnets on the tall landing skids enables it to navigate the ground robots toward the green line.

Figure 2. Aerial Robot Super Squadron

A. Propulsion and Lift system

The Super Squadron is equipped with four brushless DC motors and four propellers. Two pairs of propellers spin in Clockwise and Counter clockwise directions respectively, such that the sum of the reaction torques is zero during hovering. We change the rotational speed of the four motors in order to create relative thrust offset between the propellers and therefore the attitude control is achieved. The aerial robot has six degrees of freedom and is achieved by varying the motor speeds.



(a) *Quad rotor Propulsion and lift system* (b) *Super Squadron Platform*

Figure 3. Custom made base aerial platform

B. Guidance, Navigation and Control

B1) Stability Augmentation System

The vehicle is an unstable system, in order to make it move as expected, an attitude and heading controller is needed. There are different levels of communication with the Super Squadron: sending the vehicle direct motor commands, sending the vehicle angles (pitch, roll and yaw), sending the vehicle waypoints. The stability augmentation system is done by repeated tuning of the PID values based on trial and error method and we developed our position controller based on the results.

B2) NAVIGATION

The inertial navigation system (INS) is an efficient navigation method but accumulative errors occur. To correct this error in the INS, this paper presents a novel optical-flow aided navigation method by studying the terrain aided navigation, which can implement the continuous error estimation of the INS by employing the extended kalman filter that regards optical-flow as its measurement parameter. Therefore, this aided method is similar to the terrain aided navigation except that the measurement parameter and equation are both derived from optical-flow instead of terrain height. Experiments with some actual aerial image sequences have proven the efficiency of this aided navigation method. Moreover Optical flow would be the best alternative way to navigate through indoor corridors without the use of GPS, as Optical flow is a technique which is used to determine the motion of the surfaces of the objects in relation to the observer. It has also got the advantages of using very less power and components.

The optical flow navigation works with a downward facing camera as the major component. A multi rotor platform is chosen as the UAV with which the optical flow navigation is demonstrated. The UAV consists of an automatic Flight Control System which also includes a central processing unit. The main processor is fed with a reference image as an input. The on-board downward facing camera captures the image. The captured image is then fed to the processor. The processor then compares the captured image with that of the reference image. It is programmed using python programming language to do the sequence of actions. Python is a powerful programming language. We used python language for our programming because it is simple and has only fewer lines of code. It is considered to be the ideal language for application development. The other reason for choosing python language is that the standard library is freely available on the python website.

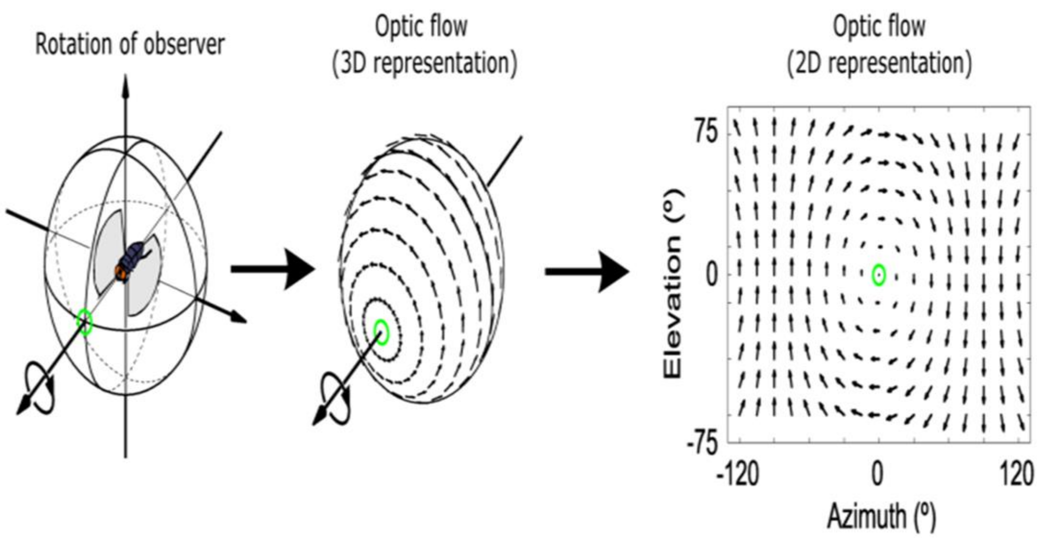


Figure4. Optical Flow

Optical Odometry: PX4FLOW is an integrated module board, combined with a CMOS camera, sonar, a frame grabber processer and a CPU. The sensor is placed at the bottom of the vehicle facing downwards and the module board provides data of the flow image, camera velocity, and ground distance. This board, by its own, can be a navigation sensor. The aerial robot could get the position feedback by performing integration on the velocity from this optical flow odometry.

C) Flight Termination System

There are three ways to achieve flight termination. The vehicle can be changed from autonomous to manual control by just flicking a switch on the RC transmitter, then the safety pilot can take manual control of the vehicle. There is also a flight termination button in our ground station, in case of emergency situations; someone can click the button to control the vehicle in a descent. The third way is the use of kill switch as per the mission rules which can be operated by the referee in order to kill the device.

III. PAYLOAD

A) Sensor suite

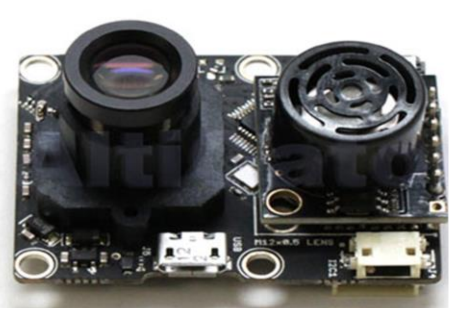
a1) GNC Sensors

Super Squadron quadrotor is a custom made quadrotor which is designed to be extremely stable, robust and safe platform. The on-board sensors include laser range finder, inertial measurement unit, cameras, optical flow sensor. The Inertial Measurement Unit and optical flow sensors are connected to the autopilot board, laser range finders and cameras are connected to the on-board computer. An off –the- shelf optical flow sensor is used for attitude stability and position control. High speed vision light cameras are used for target detection and tracking and these cameras can provide 752x480 colour images at a speed of 87fps.

(a) LIDAR

(b) Ultrasonic sensor

(c) Vision Light Camera



(d) Optical Flow sensor

Figure 5.Various on board sensors

a2) Mission Sensors

a21) Target Identification

Tracking multiple moving objects from an unsteady aerial platform has major challenges like fast camera motion, changing scene and lighting, and targets entering and leaving the field of view at arbitrary position. To overcome these difficulties, a vision system is developed that is capable of detecting and tracking multiple objects of interest. Our approach makes use of algorithms with the particle filter using colour histogram as observation feature. It is a powerful technique for tacking multiple targets. The colour-based particle filtering process enables us to efficiently and reliably track the individual objects. However, the design of proposed distribution and the treatment of objects entering and leaving the scene are two crucial issues. In this paper, we incorporate information from HOG-based SVM detector.

The offline learned SVM detector has two major functions in the tracking system. One is to initialize the starting states of particle filter automatically and add new objects entering the scene quickly. The other is to improve the proposal distribution for the particle filter. Histograms of oriented gradients (HOG)6 is a vector form feature descriptors which has been successfully used in object detection. We apply the HOG descriptor to encode the shape information of the targets. Since the HOG descriptor operates on localized cells, HOG descriptor is robust under viewpoint and lighting changes, and can be computed efficiently.

a22) Threat avoidance

Obstacle/threat avoidance is programmed in the mission planning section. Since the rules of IARC7 requires that the aerial vehicle should not touch any of the obstacle robots and as it is mandatory for the serial robot to showcase this behaviour of obstacle avoidance in order to accomplish the mission successfully. Our vehicle would avoid getting close to the moving obstacle. The velocity of the obstacle would add a force to the vehicle and thus preventing it from collapsing with the obstacles.

B. Communications

Super Squadron uses a wireless Xbee module which is attached to the on-board computer as well as to the ground control station for providing the data link between the aerial vehicle and the ground station. Images from the aerial vehicle are transferred to the ground station through a 5.8 GHz wireless image transmission unit.

C. Power Management System

The Super Squadron is powered by Lithium Polymer-Ion battery. The battery is connected to a power distribution board which has four interfaces to power the ESC’s. Meanwhile, a voltage adapter is used to turn the voltage into 5V for powering the processors on-board. The SCM on-board will measure the voltage of the battery continuously during the flight and raise the alarm once under voltage happens so that we can ensure safety of flight and battery.

IV. OPERATIONS

A. Flight Preparations

a1) Check List(s)

1. Make sure the power of battery is full
2. Check 2.4GHz connection
3. Check 4x electronic speed controllers
4. Check the motor blade orientation
5. Check RC radio
6. Check the status of quad rotor and the connection of avionics
7. Power on, check the switch of control rights
8. Check the communication between the quad rotor and the ground station

Once the physical check has been completed, a functionality test must be done:

1. Power ON 2.4GHz transceiver
2. Power ON telemetry kit
3. Check LED indicators
4. Run on-board self-diagnostic program
5. Run automated checklist
6. Make a simple test flight to make sure the software system works fine

B. MAN/MACHINE INTERFACE

Man/machine interface is established by telemetry and on-board camera. The telemetry is connected with the ground station for real-time display of quadrotor flight status, including attitude, position and ambient environment and so on, which is used to judge whether the flight is normal. Telemetry is transferred to off board computer via Xbee transceiver. The camera link is established with a frequency 2.4 GHz transceiver module. Six channel RC controllers are used to switch between modules and autonomous board and also act as a kill switch.

V. RISK REDUCTION

A. Vehicle Status

Super Squadron quadrotor will transfer its flight status continuously to the ground control station via Wi-Fi during the flight. The ground station displays the properties that include attitude, height, ambient environment, camera images, battery voltage, and laser scan data and so on.

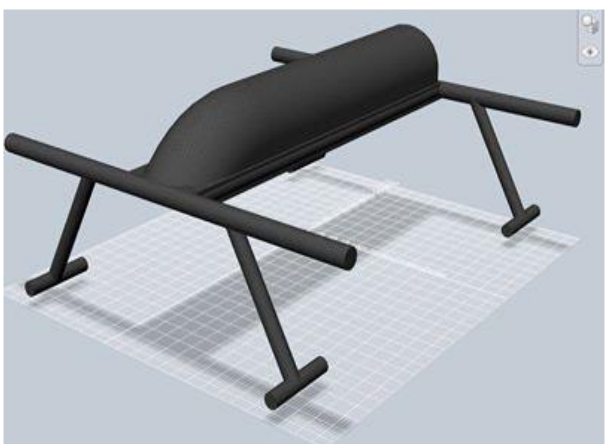
a1) Shock/Vibration Isolation

The primary source of vibrations on-board of the vehicle is from the propulsion system. The shocks are generated from the rotation of motors, which interferes the accelerometer and the ultrasonic sensors. For the ultrasonic sensors, we use anti-vibration pad for reducing the shocks. We also use rubber washers to retard the shock and at the same time filter in the software is being used to reduce the effect of shock on attitude estimation.

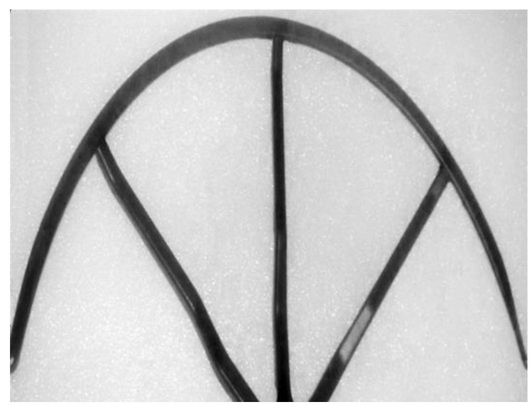
B. Safety

To ensure the safety of people and the vehicle, a series of tests should be taken before the flight, as mentioned in checklist. We have already taken safety into account when designing the system. First, we have installed a protective shield around the vehicle preventing the propellers from hitting other objects and obstacles. We have also designed emergency schemes which include manual override capabilities by a safety operator and a safety kill switch which is programmed on-board as per the mission rules ensuring the absolute right of the referee to shut down the system.

C. Modelling and Simulation



(a) 3d Sketch

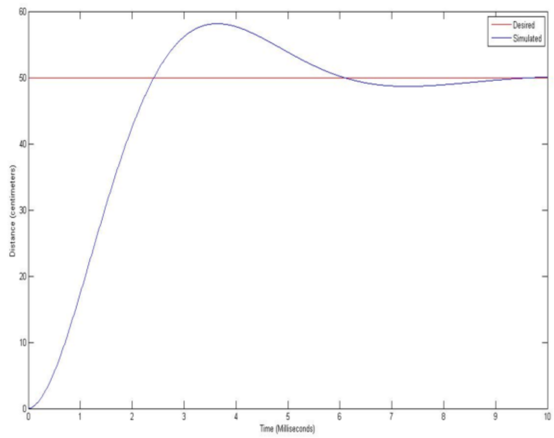


(b) 3d printed prop

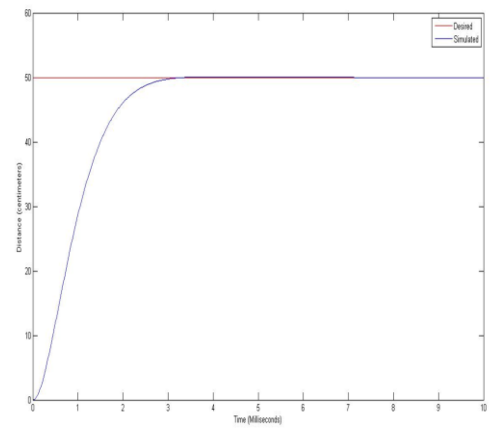
Figure6. Super Squadron 3d modelling

We used 3D software like CATIA and Autodesk 123d design for designing our Super Squadron. The overall structure and the propeller guard were completely designed using 3d modelling and was fabricated using rapid prototyping which saved us lot of time and helped us to make and implement design changes to the structure.

The MATLAB (**M**atrix **L**aboratory) has been used to simulate the Proportional Integral Derivatives (PID) graphs. Based on the graphs simulated we were able to study the PID values for a steady and stable flight.



(a) Default PID Response



(b) Tuned PID Response

Figure7. Simulated PID graphs

PID response for collision avoidance: The obstacle avoidance uses PID controller to calculate the response for the detected obstacles. The default causes overshoot and instability to the UAV. The system has been tuned to avoid overshoots and instabilities.

D.TESTING

The overall system was simulated and unit testing was done before fabrication. The design changes yielded from the simulated results were rectified using 3D design software. We also performed a bench test in order to analyse the performance of the quad rotor and the PID controller is tuned accordingly to the test results. Succeeding to these tests the aerial robot is operated in manual mode and the system's reliability is verified.

VI. CONCLUSION

This paper has detailed information about the air vehicle and payloads of the aerial robot. Our system is in the initial stages of testing and we are very much hopeful that our attempt will be successful and we expect our aerial robot to be able to demonstrate the required behaviours of mission 7and drive away more than 4 of the ground robots towards the green line.

REFERENCES

1. Marconi, L., “Aerial service robotics: The AIRobots perspective”, CASY-DEIS, Univ. of Bologna, Bologna, Italy // Published in: Applied Robotics for the Power Industry (CARPI), 2012 2nd International Conference // Date of Conference: 11-13 Sept. 2012// Page(s): 64 - 69

2. Williams, H., “Integration of Learning Classifier Systems with simultaneous localisation and mapping for autonomous robotics”, Sch. of Eng. & Comput. Sci., Victoria Univ. of Wellington, Wellington, New Zealand // Published in: Evolutionary Computation (CEC), 2012 IEEE Congress // Date of Conference: 10-15 June 2012 // Page(s): 1 – 8

3. Dalal, N., and Triggs, B. "Histograms of oriented gradients for human detection," Computer Vision and Pattern Recognition, 2005. CVPR 2005. IEEE Computer Society Conference on. Vol. 1, IEEE, 2005, pp. 886-893.

4. Zhang Yao, “Autonomous control system for the quadrotor unmanned aerial vehicle”, Tianjin Key Lab. of Process Meas. & Control, Tianjin Univ., Tianjin, China // Published in: Control Conference (CCC), 2012 // Date of Conference: 25-27 July 2012 // Page(s): 4862 - 4867

5. Carrillo, L.R.G., “Quad-rotor switching control: An application for the task of path following”, Heudiasyc UMR 6599 Lab., Univ. of Technol. of Compiegne, Compiegne, France // Published in: American Control Conference (ACC), 2012 // Date of Conference: 27-29 June 2012 // Page(s): 4637 - 4642

6. Ferrick, A., “UAV obstacle avoidance using image processing techniques”, Dept. of Electr. Eng. & Comput. Sci., Case Western Reserve Univ., Cleveland, OH, USA // Published in: Technologies for Practical Robot Applications (TePRA), 2012 IEEE International Conference // Date of Conference: 23-24 April 2012 // Page(s): 73 - 78

7. Saini, M., “Anonymous surveillance”, Sch. of Comput., Nat. Univ. of Singapore, Singapore, Singapore // Published in: Multimedia and Expo (ICME), 2011 IEEE International Conference // Date of Conference: 11-15 July 2011 // Page(s): 1 - 6