# Development Of An Autonomous Aerial Vehicle Capable Of Indoor Navigation

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**Abstract**

Team *Swift* of Indian Institute of Technology Madras is participating in the 19th edition of International Aerial Robotics Competition conducted by the Association for Unmanned Vehicle Systems International. The problem is to find a target which is identifiable by a warning tone and a set of blinking Light Emitting Diodes (LEDs) using an autonomous aerial vehicle. A video of the display present on the target is to be transmitted at the end. The display is identified by a blue LED below it. The approach to the solution involves a quadrotor helicopter enabled with a combination of Stability Augmentation System for stability, Simultaneous Localization and Mapping for positioning, Image processing and Sound signal processing for target detection and Nearness diagram method for obstacle avoidance. This paper epitomizes the design of the various components and subsystems of the aerial robot.

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## INTRODUCTION

### Statement of the Problem

An aerial robot must enter a building, and navigate through it to find a designated control panel. The control panel is identified by a set of blinking lights, and an alarm sound. The arena is about *21m*x*36m* whose internal layout is unknown. The maximum dimension of the robot is 1m and it should weigh less than *1.5kgs*. To complete the mission the robot must stream at least *5 seconds* of video of a display present on the afore-mentioned control panel with sufficient resolution so that it can be read by the judges. The entire mission must be completed within *10 minutes*. Processing may be done at an external base station which facilitates the use of computationally intensive processing[1].

### Conceptual Solution to Solve the Problem

quadrotor vehicles are not stable by themselves. So we need to have a Stability Augmentation System (SAS) which stabilizes it. This is at the lowest of the three levels in the overall system architecture(Figure 1) since it has to be quick in response. The quadrotor used is purchased from *Ascending technologies* and it already has an SAS for maintaining it horizontal. It takes input from the Inertial Measurement Unit (IMU) on board and controls the lift provided by each propeller so as to maintain the vehicle horizontal.

In the next level of system architecture we have an obstacle avoidance and velocity control system. This takes in the two-dimensional obstacle profile from the Light Detection and Ranging (LIDAR) continuously and commands the base vehicle so as to reach the local target specified by the higher level (Mission Planner level) while avoiding all the obstacles on the way. This system also computes the control inputs needed to move the robot at required velocity and transmits it to the primitive driver.

The Mission Planner and Local target Identifier system is the highest level. This system takes in the input from the LED detection, exit detection, Simultaneous Localization And Mapping (SLAM) and Acoustic direction detection modules and intelligently decides the local target based on the mission rules and our target searching strategies. It passes on the local target coordinates to the lower level which tries to achieve it

Figure1 shows the overall architecture of the system. The blue colored oval shapes correspond to the sensors on board. The green colored boxes refer to different algorithms. The orange colored boxes refer to different levels of controllers.

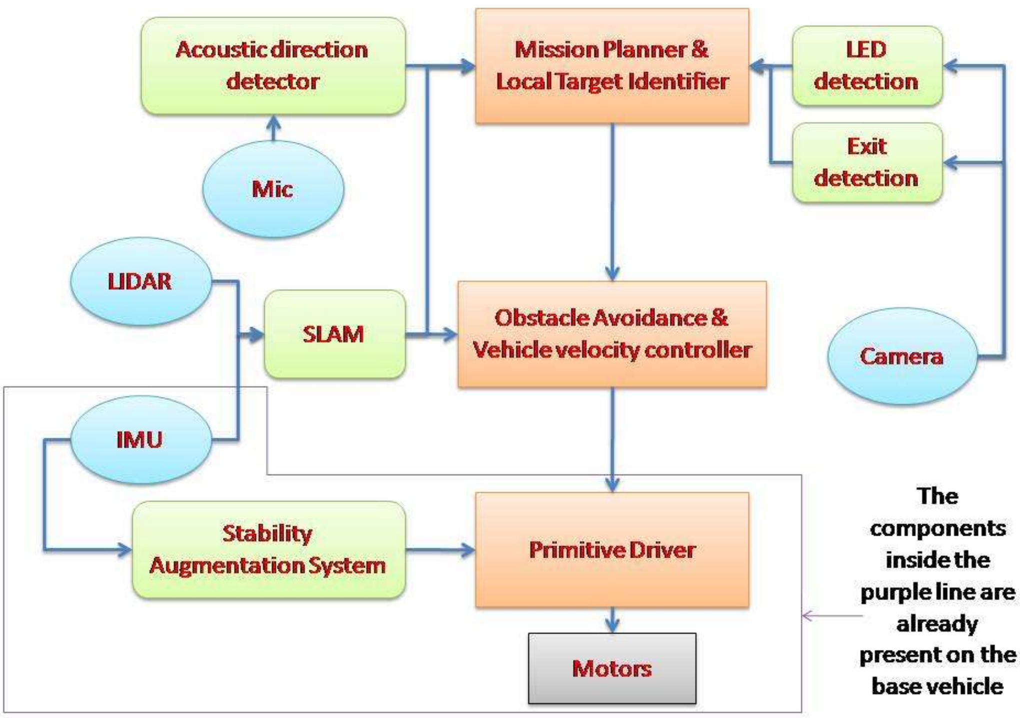



*Figure 1. Overall system architecture*

## AIR VEHICLE

### Propulsion and Lift System

The aerial vehicle is a quadrotor. Figure 2 shows the aerial vehicle. Four motors are fixed at four corners of a square. Each motor is stepped down in RPM, and the rotors placed opposite to each other rotate in the same direction. Torque on the body can be made zero by having a set of two rotors rotate in clockwise and the other set in anti-clockwise direction. The propellers are such that thrust from all rotors is upwards and almost equal.

The mechanical frame is made of a combination of Balsa wood and Carbon fiber plates. The Central frame is made out of aluminum. This frame encases the Electronic circuits. A casing for the battery is custom made and placed at the bottom. A mount is constructed out of aluminum, to accommodate the LIDAR.

*Figure 2. Picture of the aerial vehicle*

### Guidance, Navigation and Control

*Stability Augmentation System*

The quadrotor is not a stable flying vehicle. We need to have a control system which stabilizes it. In the Unmanned Air Vehicle (UAV), we have circuitry and algorithms which control the speed of each of the four brushless motors in order to maintain the vehicle in horizontal position. It has accelerometers and rate gyros. The accelerometers give accelerations and the gyros give the rate of rotation about all the three axes. Under static conditions of the vehicle, the accelerometer values are directly related to the tilt of the vehicle. Under dynamic conditions, the lateral accelerations of the vehicle are also detected by the accelerometers. So data from the gyros and accelerometers is used to compute the actual tilt of the vehicle. The on board ARM™ processor is used for this data fusion. These calculated tilt values are used for stabilization of the vehicle. The vehicle uses a Propotional Derivative (PD) control[2] for stabilization. The vehicle can be set into a mode called X-Acc mode which stabilizes the vehicle. The computer controls the vehicle by setting the set-point of the pitch and roll control systems. Set-point is the value which the system tries to achieve. The vehicle tries to achieve these pitch and roll set-points (given by the computer) using a PD control. The difference between the desired value of pitch and the actual value of the pitch is called error in pitch. In PD control, this error and its derivative are multiplied by suitable constants and their sum is given to the Electronic Speed Controllers of the Brushless motors. These control the speed of the Brushless motors accordingly. Thus the pitch is maintained at the desired value. roll is also maintained similarly.

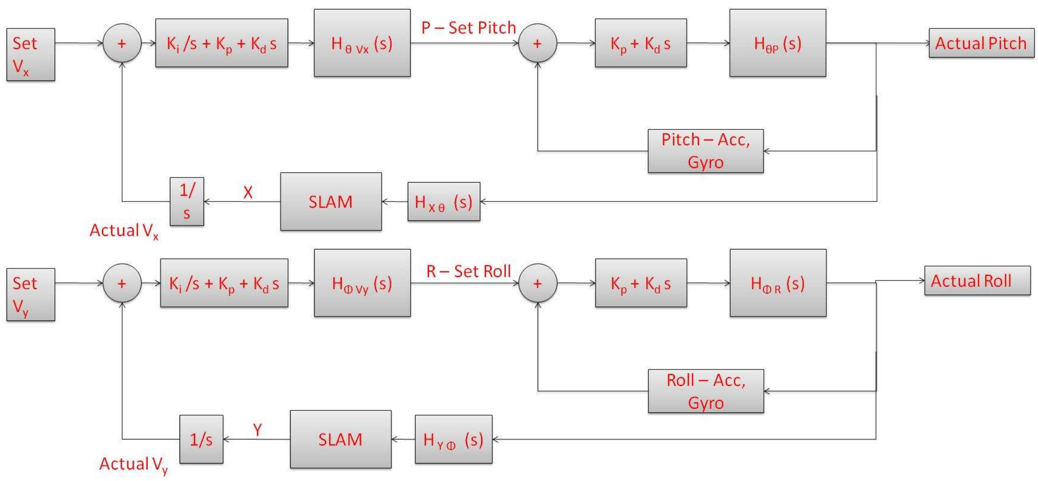
*Navigation*

Navigation of the vehicle consists of Obstacle avoidance, SLAM and control to achieve the desired velocities and heading. The Mobile Robotics Programming Toolkit library[3] is used for implementing SLAM and Obstacle avoidance.

The obstacle avoidance of the vehicle is based on the Nearness Diagram algorithm[4], which facilitates high-speed reactive navigation. Nearness diagram is a real-time collision avoidance algorithm which carries out high-level information extraction and interpretation of the environment, using this information to generate motion commands. A two-dimensional scan data from the LIDAR and the local target are given to the algorithm, which then computes the direction to be followed by the UAV and its linear and angular velocities.

The aerial vehicle is expected to navigate in GPS denied environments and hence the only way of estimating the position of the vehicle is to use the IMU. However, the errors in the data obtained from the IMU accumulate over time and the estimated position of the vehicle is inaccurate. In order to improve accuracy, readings from the LIDAR and the IMU are given to a SLAM algorithm [5] based on Iterative Closest Point (ICP). The algorithm generates a map of the surroundings while keeping track of the local position of the vehicle. The position values computed from the SLAM program are used to correct drifts in the IMU readings. Mapping ensures that the UAV does not enter the same room twice.

The position and velocities of the vehicle are updated from SLAM at a rate of about *40Hz*. The obstacle avoidance algorithm outputs the horizontal velocities required in Global X and Global Y direction. We have a PD control loop[2] over the X, Y velocities to maintain them at the value required by the Obstacle avoidance algorithm. We accelerate in a particular direction (local X or local Y) by changing the set-point of pitch/roll. We try to maintain the velocities by controlling the values of pitch and roll set-points



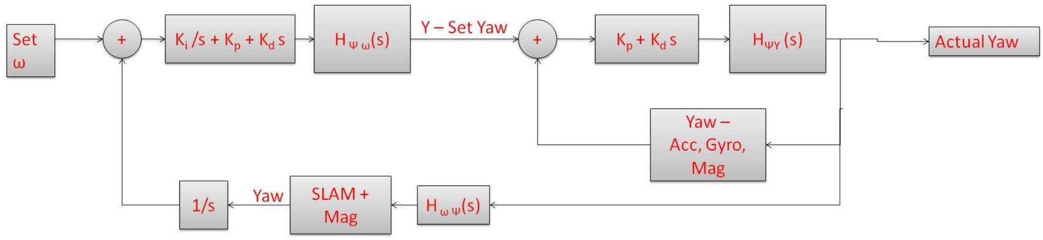



*Figure 3. Control system architecture*

### Flight Termination System

Once the mission is completed successfully and the images and video are sent, the UAV slowly descends to the ground and switch off autonomously, or the UAV will be made to land manually. In case of an emergency or malfunctioning of the robot, we provide a kill switch which the judges may use to shut the vehicle down immediately. This switch will be independently powered and will have its own Radio Control (RC) channel for transmission.

## PAYLOAD

### Sensor Suite

The sensors aboard the X3D-BL™ comprise of rangefinders, audio sensors, visual sensors, pressure sensors, gyroscopes, accelerometers and magnetometer.

*Hokuyo URG-LX Laser Range Finder*
It is a two-dimensional laser range finder with a range of *4m* and a field of view of *239.770*. The scan data and the data from the IMU are given to an ICP based SLAM algorithm [5] which makes a map of the surroundings while simultaneously keeping track of the vehicle's global position. The scan data is also used to identify the obstacles in the vicinity of the vehicle and aids in obstacle avoidance. This data is also used to reduce drift and hence increase stability.

*Inertial Measurement Unit*

The IMU consists of three single-axis gyroscopes, one triple axis accelerometer and a magnetometer . The data from these sensors is combined using data fusion algorithms running on an ARM$^{TM}$ Processor with an update rate of *1kHz*. The yaw data given by the yaw gyro is corrected using the onboard magnetometer. The calculated global accelerations and altitude are output over a serial link and is relayed to base station using a Zigbee module.

*Unidirectional Microphone*
It is used to determine the direction of source of the audible warning tone. It is connected to the audio jack of the Gumstix Summit expansion board. The audio data is transmitted via a Wi-Fi (IEEE 802.11g) link to the base station, where it is processed digitally to find the direction.

*Monocular camera*
The USB 2.0 webcam gives out a *24-bit 352x288* video stream at *15 fps*. It is connected to the Gumstix Overo board which filters it and transmits it to the base station.

*Sound Navigation and Ranging (SONAR)*
The SONAR gives out range data over a RS-232 interface to the Gumstix which transmits it to the base station for processing. The data obtained from the SONAR is used to determine the altitude of the vehicle.

*Local Target Detection*
The local targets of the vehicle consist of the entry window and openings within the building to enter the next room. The data from Sound processing system is used to preferentially select possible openings. The entry window is characterized by the presence of Ukrainistani National seal above it. An algorithm based on Hough Transform[6] is used to detect rectangular openings and the seal is identified using image segmentation. LIDAR is also used to identify the openings.

*Final Target Detection*
The final target is a control panel, which can be identified by various blinking lights and audible warning tone. It also contains a blue non blinking

LED. The lights are characterized by high intensity of color and brightness. Once the lights are identified, they are tracked using optical flow[7]. The video is analyzed frame by frame to find if the lights are blinking or not. After the blinking lights are identified, we need identify the blue non-blinking led. For this purpose, the Hue values of the light sources are analyzed. The regions having the Hue values of blue can be identified. The image processing involves various smoothing techniques, histogram equalization, various thresholding and motion tracking methods. The sound source is identified using a unidirectional microphone. The data from the microphone is processed digitally by a LabView™ Virtual Instrument which determines the direction of the sound emitter. The processing includes finding Fast Fourier Transform (FFT), filtering, peak detection and optimization.

### Communication

The comunication with the vehicle and the onboard sensors is done through two wireless links

*Control Communication*
The base station relays control commands to the UAV using an IEEE 802.15.4 2.4GHz wireless link established using a X-Bee pro module.

*On-board Processor Communication*
The on-board ARM™ processor communicates with the base station using a IEEE 802.11g 2.4GHz wireless link established using a Wi-Fi module integrated with the Gumstix Overo board. The audio, video, LIDAR and SONAR data are transmitted through this link.

### ***Power Management System***

A 11.1 Volts Lithium Polymer (Li-Po) battery is used to power the motors and the electronics on-board. For electronics requiring lower voltages switchers from national semiconductors are used to step down the voltage from 11.1 V to 5 V and 3.3 V. Switchers are preferred over the conventional voltage regulators because of their low power dissipation rates in the form of heat.

## OPERATIONS

### Flight Preparations

*Preparation Before Entering the Arena*

The preparation before entering the arena includes making a code to check the integrity of all the software and firmware. A list of tests will be made to check all the individual components and systems. At this point we are not in a position to give a list.

*Preparation At the Arena*

Set up and boot the computers. Switch on the power supply on the robot. Initialize communication between the robot and the ground station. Run through the hardware check list and the Integrity check code. Set the trims. Start the flight

### Man/Machine Interface

Time tagged position and velocity status messages are transmitted to the judges' Common Operating Picture (COP) using JAUS compliant messages. The mission is started when a Resume message is received from the judges' COP. The mission is terminated when the target is identified or if a Shutdown message is received from the judges' COP. For emergency shutdown of the vehicle a manual kill switch is activated causing the vehicle to land immediately.

## RISK REDUCTION

### Vehicle Status

The main structure of the UAV is made from Magnesium, Aluminum and Glass fiber- balsa composite and provides protection to the electronic circuits mounted on the vehicle. The landing gear is such that it provides adequate suspension so that the UAV is not damaged by the impact, even if it drops from a height of over two meters. We are using a secured Wi-Fi link to prevent interference from other frequencies. By constantly monitoring the voltage and current data from the robot, we are estimating the flight time left. We also intend to monitor the temperature and vertical speed for any sudden changes in their values.

### Safety

*Battery*
The battery is placed in a specially designed casing under the electronics of the UAV.

*Protective rings*
The UAV is protected by a ring around each of its propellers, which prevent the propellers from coming in contact with any obstacle, even in the unlikely event of a collision.

*Voltage regulation*
The power regulation circuits on-board ensure that the voltage supplied to each electronic component does not exceed its rated value.

*Protection to LIDAR*
The LIDAR is protected by a Styrofoam casing over its blind spot and Depron padding under it. This helps in protecting the LIDAR in case of any head down collision.

## CONCLUSION

This paper briefly discusses our approach to solving the challenge posed by the 19th edition of International Aerial Robotics Competition. Machine Vision and obstacle avoidance algorithms have been implemented on the aerial vehicle to identify and reach the target, while avoiding obstacles along the way. Problems encountered and solved during the development of the aerial vehicle include wireless communication, navigation in highly cluttered environments, inter-process communication, localization, real-time target tracking and insufficient payload capacity. The work can be extended to a swarm of mutually coordinated UAVs.

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