AUVSI SUAS COMPETITION TEAM LAKSHYA MSRIT JOURNAL PAPER

Preamble

Embarking on a journey to build an autonomous Unmanned Aero Vehicle (UAV) and to the be the best amongst an international lot who look to take such journeys led to the project christened 'Lakshya'

Lakshya is pioneering the field by being the first group of students from M.S.Ramiah Institute Of Technology (MSRIT). Also Lakshya is the first team to participate in the competition- Student unmanned systems (SUAS) to be held under the ageis of Association for Unmanned Vehicle Systems International (AUVSI) , Maryland USA, to be held on the 19 -06-2011.

From being the uninitiated lot to the team now wanting to prove to the world that we are among the best, the bold steps of taking up this project and seeing it to the crowning glory of success is the chronicle presented below.

Contents

1. Abstract

At the outset, the project is to exploit the capabilities of the UAV for imagery applications as well as for development of open source autopiloting systems.

In doing so Lakshya has successfully integrated the following operative package with the UAV as the platform.

The UAV in itself has been designed and built by Lakshya. The Balsa wood and foam fuselage derives its power from a battery driven Turnigy SK-3542 900kV electric motor, optimized for imagery applications and with capabilities to further enhance open source autopiloting systems. The Camera being used for Imagery by the aircraft is GoPro Surf HD. The autopilot system is a Tiny 2.11 Paparazzi system, an open source autopilot.

The aircraft is being controlled through a computer on ground via a 2.4GHz Futaba 9CAP Radio Transmitter. The telemetry is being handled by the Xbee XSC PRO modems.

In pioneering this UAV project, every avenue has been explored to keep abreast with the latest developments in the field and every effort has been made to incorporate the same in the present execution. This is apart from adhering to the framework of the competition's rules of engagement.

2. Team Lakshya-

1. Prasanna Raghunathan
2. Prateek Khanna (Team Captain)
3. Srikanth Singh
4. Rajarshree Rahul
5. Vishnu B.N
6. Dr. S. V. Prakash (Project guide)
7. Dr. Prashanth. T (Project mentor)

3. Systems Engineering Approach

With a start date set for March 2011, and in order to optimise the time to the competition, Team Lakshya envisaged a multi stage project programme which was planned and executed as follows:-

1. *Mission Analysis Stage*:
   Analysis of Mission requirements, formulation of the technical overview and arriving at finite technical and physical deductions for execution
2. *Prototype stage*:
   - Construction of the prototype within the mission's framework
   - Testing of prototype and data collection, collation, repetition trails
   - Flight testing under different conditions- primarily controlled manually by a radio transmitter
   - Payload efficiencies and other parameters evaluation.
   - Failure Mode Analysis was carried out. (Electronic failures, airframe failures)
3. *Rebuilding Stage*:
   After evaluating the various performance of prototype model, major and minor faults have been eliminated and an improved failsafe model has been constructed. The aircraft has been flight tested again and its payload capabilities were analysed. All niggles and issues with the performance, efficacy has been addressed along with the administration of the refinements in specifications.
4. *Integration of Autopilot*:
   With a failsafe airframe with proven capabilities on hand, the Auto pilot system integration has been carried out and extensive aircraft trails have been executed.
5. *Final Testing stage*:
   The fully integrated aircraft in the final form has been subjected to autonomous flights, checking for consistency, efficiency on a routine schedule logging in about 50 hours of flying time. Final testing of the imagery payload has been extensively conducted.

4. The Systems Overview

The Aircraft system is built of

1. The Airframe
2. The Electronics, including the Autopilot
3. Camera and image processing unit

Team Lakshya indigenously designed and built the fuselage and tail boom using traditional materials- balsa wood and foam. Fibre tapes form the bulk of the reinforcements where required. The wing is an off the shelf fixed type with a wing span of 58.34 in. The landing gear has been fabricated to optimise the airframe design for best payload management.

The electronics of the aircraft - Turnigy 3542 electric motor, the Li-polymer battery, telemetry systems -Xbee XSC Pro, the Autopilot (inclusive of the LPC-2148 processor, Ublox LEA 4H GPS, Infrared sensors), and the servos are housed in the fuselage.

5. System Design and Component overview

5.1 Airframe

The team believed in building its own airframe, as it enhances the team's experience of flight construction and in the process has been able to analyse and eliminate faults in the airframe. The team experimented with a number of airframe designs, built about 3 to 4 fuselages and sets of wings before freezing and selecting the current form and function.

Team Lakshya has built its own foam cutter in order to make the wing for the aircraft. A Ni-chrome wire tied across the ends of a U shaped structure and connected to a transformer supply provided the required heat to cut/shape the foam to form the wing. Incidentally, the wing built by the team ended up with the span being too long requiring additional reinforcements. The span would then be of 6 feet with 6 separate blocks of 1 foot each. The additional reinforcements meant increase in weight to the aircraft threatening the feasibility of the chosen mode of propulsion- an electric motor and would lead to a strain on the battery, effecting payload efficacies. In order that this issue be addressed, an off the shelf, fixed wing made of Expanded Poly Propylene has been outsourced and fitted to the airframe. The fuselage is made of balsa wood exploiting the lightness of the material.

5.2 Aircraft Specifications

S.No	DESCRIPTION	VALUE
1.	Gross Weight	7.2lbs
2.	Wing Span	58.34 inches
3.	Flight/Cruise Speed	14 to 18 m/s
4.	Endurance	60 min
5.	Power Plant	605W electric motor
6.	Mean Aerodynamic Chord Length (MAC)	9.05 in.
7.	Planform Area	3.666 ft2
8.	Aspect Ratio	6.5
9.	Propeller	APC 11” x 5.5

5.3 Aircraft engine and Propulsion

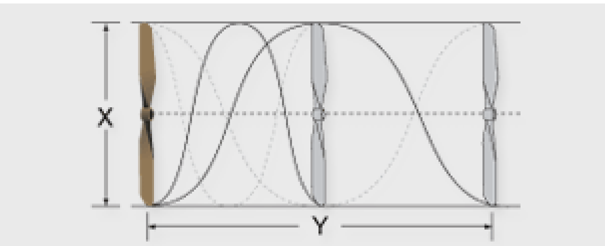
In the prototype stage, the team tried out a gas run 2stroke 7CC engine, but abandoned the same owing to the higher noise and vibration levels during flight. The vibrations negatively impacted the quality of imagery and the functioning of the servos. The gas tank occupied too much space, reducing the payload capability and increasing the overall weight of the aircraft negating efficiency.

The team switched to an Electric motor for the propulsion of the aircraft, electric motors proving to be vibration and noise free and occupy a considerably less amount of space. On analysis of the Watts per pound calculation, it was estimated that the aircraft required a thrust of about 1kg. This helped the team zero in on the Turnigy-SK 3542 propulsion mechanism which is capable of producing a thrust of 1.1 to 1.5 kg, allowing the aircraft to fly comfortably even on partial throttle which meant added battery savings. The specifications of the motor are as follows:

Model: **SK35-42** **1000**
Kv: 1000rpm/v
Turns: 5
Resistance: 48
Idle Current: 1.7A
Shaft: 4mm
Weight: 142g
Rated Power: 605w
ESC: 45A
Cell count: 3~4 Lithium polymer
Power output: 0.15 to 0.25 glow engine

A Lithium polymer battery used as the power source has a capacity of 5000mA providing for an average flight time of about 1 Hour. The 9X6 inch propeller made of reinforced fibre plastic is directly driven by the motor without any gear drive mechanism. The propeller is a standard off the shelf APC e-style with the following parameters.

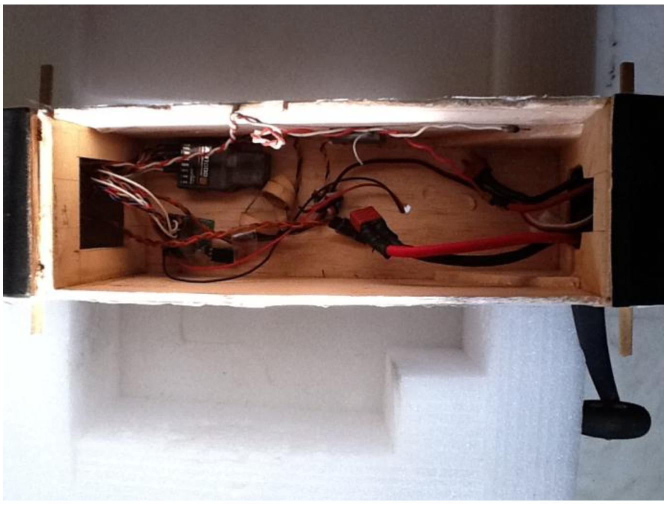
Length (Inch [X])	9
Pitch (Inch [Y])	6



5.4 Speed Controller

A speed controller of 60 Amps is being used with the motor. The speed controller regulates motor throttle while increasing the efficacy of the battery. Given the aircraft size, a 30 Amps speed controller would suffice, but Team Lakshya chose to use a 60 Amps speed controller to accommodate higher payloads. The added advantage of this controller is the low amount of heat dissipated keeping the aircraft cool whilst extending the battery range.

5.5 Payload Bay



The design of the aircraft has been arrived at to maximise payload capabilities for the mission. The Mission requires the aircraft to carry a camera for the prime purpose of Imagery. In order to enable higher payload capabilities, a 60 Amp Speed Controllers is being used. The payload bay on the aircraft is estimated to be capable of carrying a payload weighing up to 5kg, and yet consuming frugal amounts of power and capable of running at lower ranges of throttle.

5.6 Autopilot

Though a number of options / choices for autopilots are commercially available, Team Lakshya decided to use an open source autopilot. The benefits of this choice are multi-fold, in the sense that this option offers both the challenges in building and integrating the autopilot as well as options to exercise selection of various options of the system. After extensive research and analysis on open source autopilots, the team zeroed in on using the Paparazzi system. The Paparazzi system deployed tiny 2.11 in conjunction with the UBLOX LEA-4H GPS.

5.6.1 About Paparazzi

A free open source system intended for deployment of versatile autopilot systems, Paparazzi, is among the most popular of its kind. The Paparazzi eco-system is highly developed and envelops both hardware and software subsystems including GPS receivers, voltage regulators and the ever expanding array of ground station systems. The graphical user Interface is both intuitive and robust allowing multiple users. Among the key factors that favour use of Paparazzi system is the ability of the system is the ability to get the job done without the need for ground calibration and the ability to recover from any launch attitude.

Team Lakshya has deployed in this project hardware and software systems based on Paparazzi.

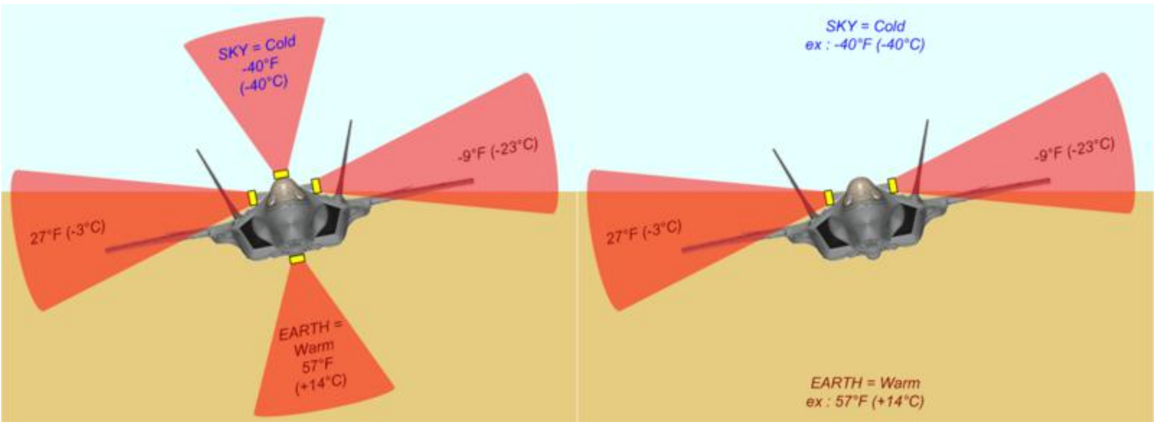
5.6.2 Paparazzi Hardware

5.6.3 On Board Processor

The Paparazzi deployed by Team Lakshya adapts AHRS (attitude and heading reference system: uses IMU data + extra (airspeed/GPS/baro/...) in the form of an LPC-2148 processor, in place of the IMU. LPC2148 is an ARM7TDMI-S based high-performance 32-bit RISC Microcontroller with Thumb extensions 512KB on-chip Flash ROM, In-System Programming (ISP) and In-Application Programming (IAP), 32KB RAM, Vectored Interrupt Controller, Two 10bit ADCs with 14 channels, USB 2.0 Full Speed Device Controller, Two UARTs, one with full modem interface, Two I2C serial interfaces, Two SPI serial interfaces Two 32-bit timers, Watchdog Timer, PWM unit, Real Time Clock with optional battery backup, Brown out detect circuit General purpose I/O pins. CPU clock speed up to 60 MHz, On-chip crystal oscillator and On-chip PLL.

5.6.4 Infrared Sensors

The paparazzi autopilot system customised by team Lakshya uses infrared thermopiles primarily for pitch attitude sensing. The theory is that at zero bank or pitch angle, the difference in the heat between the two sensors must be zero, and at 90 degrees it should be maximum. From this relationship a linear regression is made and angles are calculated during flight.

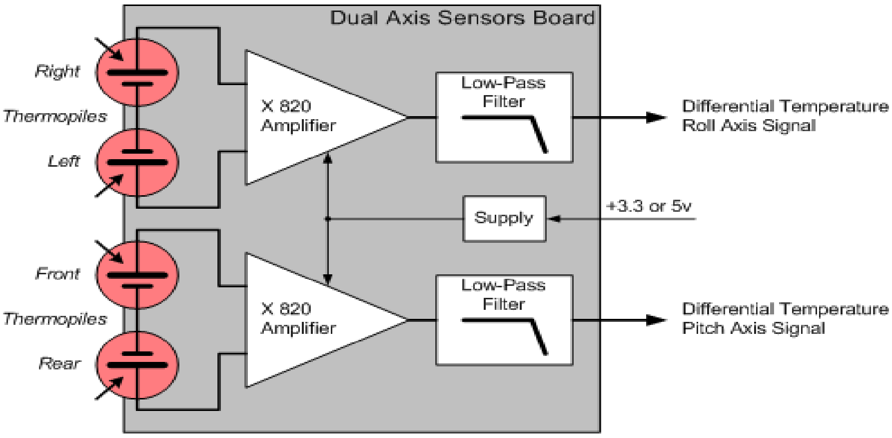


3 pairs of sensors are employed for the measurement of pitch and roll to enable deployment of autopilot systems. This 3 pair sensors array provides for better results as it eliminates the need for ground calibration which would otherwise be essential in the x-y array.

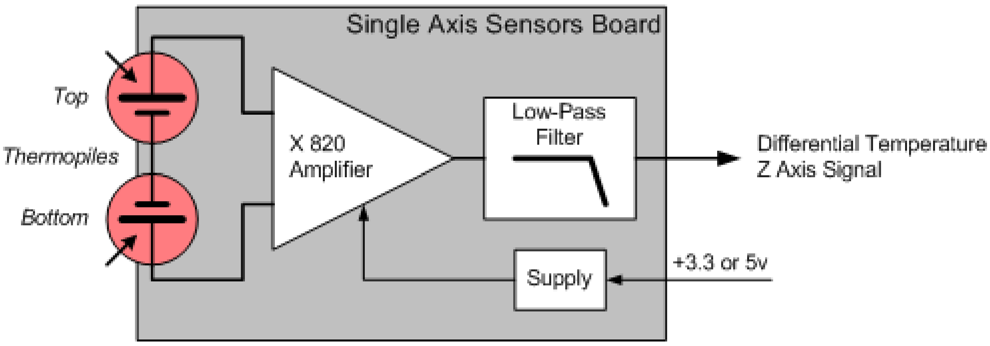
5.6.5 Hardware Architecture

The hardware architecture of the 3 pair sensors array provides is depicted below.

Horizontal Board



Vertical Board



5.6.6 GPS

The GPS being used by the team is a UBLOX LEA 4H. The choice of the GPS was zeroed in owing the following advantages on offer:

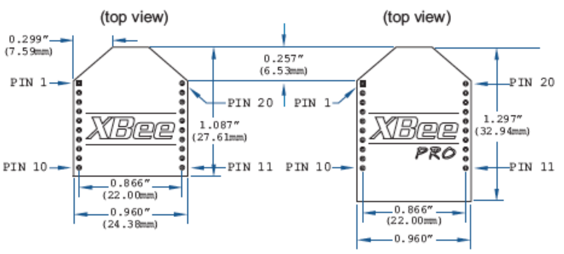
- Comes with 16 channel Antaris 4 positioning engine

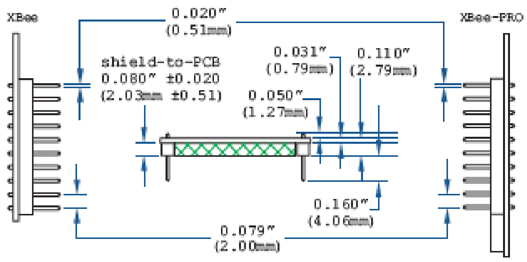
- Supports WAAS, EGNOS MSAS and DGPS
- In built power savings mode.
- Inbuilt 5 µA current back up.
- Configurable UART voltage levels and I/O
- Working support for both active and passive antennas
- Ability to detect and enable protection for antenna short and open circuits.
- Does not require external hardware reset upon power brown protection.
- Operating temperature range: -40 TO 85°C

Also, the LEA-4H module consumes low power, comes with a small foot print of 17 x 22 mm including the USB port and is highly sensitive. With a tracking sensitivity of -158 dBm the ability extends to positioning coverage in places where GPS is not possible. This module is also capable of coverage with the usage of smaller or covert antennas.

5.6.7 Telemetry

The team is using a 900 MHz XBee-PRO XSC pro modems in the telemetry unit. Ease of use and efficiency were the primary factors in choosing the XBee-PRO XSC. The XBee-PRO XSC are capable of Outdoor RF line-of-sight range up to 15 miles (24 km) with high gain antenna and Outdoor RF line-of-sight range up to 6 miles (9.6 km) with dipole antenna.

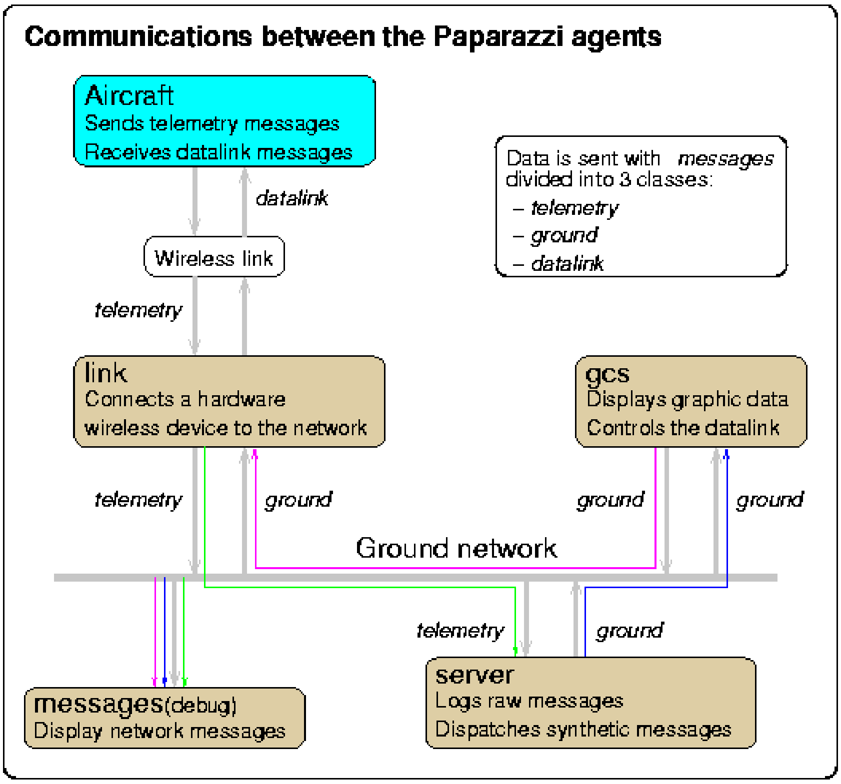




The XBee-PRO XSC OEM RF modules are extended-range 900 MHz devices providing end-point connectivity to devices. The modules are capable of deployment in point-to-point, peer-to-peer and point-to-multipoint networks. The versatility was the proving point for the choice of modems for telemetry.

5.6.8 Communication between Ground Station and Aircraft

The communication between the ground station computer and the Aircraft has been established through the Xbee XSC PRO Modems. Either the high gain antenna or the dipole antenna can be attached to the ground station computer, depending completely on the desired range of telemetry.



5.7 Radio transmitter and Frequencies being used

Team Lakshya has deployed the use of a Futaba 9CAP radio transmitter. The transmitter offers 9 channels. The advantage of using the Futaba 9CAP is channel assignability. The channels from 5-8 could be placed on any switch or slider in a single step, and channel 9 (switch only) could be placed on any switch comfortably. On most of the radios channels, 6, 7, and 8 are preassigned to a dial and a lot of finagling has to be done to get them to a switch.

Frequencies Used:

1. Transmitter Frequency -2.4 GHzAutopilot : 1. Manual - 2.4 GHz

   2. GPS - 1600 MHz

   3. Telemetry- 900MHz

5.8 Ground Station Control

With Paparazzi autopilot system being open source, the task of setting up a ground station has been simple. Most of the code is available via the user groups, allowing for customisation using C programming language where and when required.

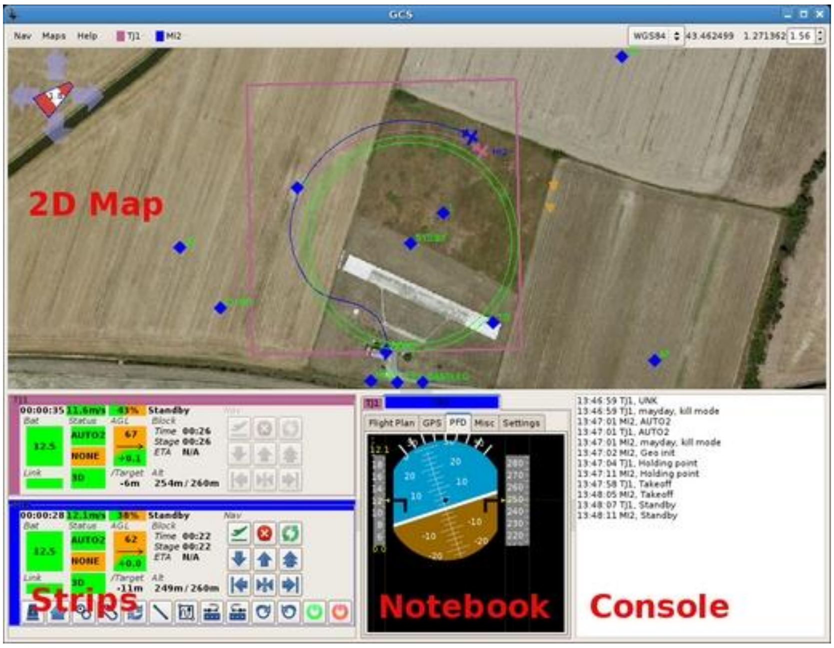
The ground station control is via a computer, running Linux Ubuntu for seamless integration with Paparazzi.

5.8.1 Ground Station Control software

Paparazzi ground station software has been installed on the ground station computer.

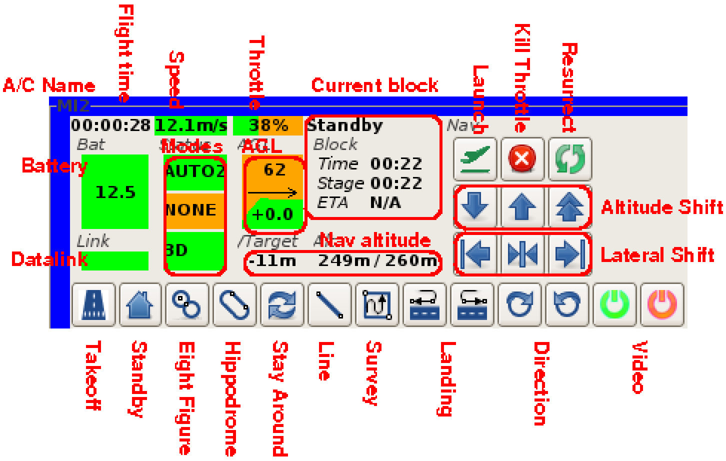
1. Linux Ubuntu operating system has been selected for seamless operability.
2. The packages for the Paparazzi have been installed using Synaptic Package Manager.
3. The sources have been downloaded from the git repository.
4. The ports have been granted access by copying the rules file: (export PAPARAZZI_HOME=~/paparazzi; export PAPARAZZI_SRC=~/paparazzi; sudo cp $PAPARAZZI_HOME/conf/system/udev/rules/10-paparazzi.rules /etc/udev/rules.d/)
5. The binaries have been compiled from the sources (cd paparazzi && make)

A sample of the paparazzi GUI along with the extract of the capabilities and explanations are reproduced here for clarity.



5.8.2 Strips

Each A/C has an associated strip that displays information about the A/C and provides buttons for common commands. The strip has the following layout by default. Paparazzi GCS is very flexible and the strip can have more or less buttons according to your configuration.



Left Side: Consists of the Flight information

Center: Consists of Navigation information

Right Side: Consists of Navigation control

Bottom: Consists of Custom navigation and setting buttons

5.8.3 Actions

Every change in the waypoints (position or/and altitude) must be confirmed with the dialog box that appears after the move. A modified waypoint remains animated on the map and the GCS continues to re-send the move request until confirmation is received from the aircraft. When clicked, the **Mark** button places a mark on the map at the A/C position. A snapshot from the video plugin is associated to this mark and can be viewed by moving the mouse over the mark. A click on the mark opens a dialog box allowing deletion of the mark.

5.8.4 Waypoint Editing

The properties of any waypoint in the currently loaded flight plan can be modified by two methods:

- Drag and drop the waypoints to a new location (a confirmation dialog will appear).
- A single left click on a waypoint opens a dialog box where you can edit the waypoint's coordinates and altitude.

Waypoint edits are sent to the aircraft immediately upon confirmation in the dialog box. The GCS will re-send the data and the waypoint will animate until the aircraft confirms receipt of the move request. New waypoints cannot be added during flight.

6. Imagery

After successfully completing the airframe and the integration of the autopilot, the next mission requirement to be tackled by Team Lakshya was Imagery. A camera was needed for the same. Team Lakshya experimented with a wide range of cameras available in the market. None of the consumer electronic cameras seemed to exhibit the performance required by the mission. Team Lakshya then heard of GoPrO cameras and on conducting a survey on the models available with GoPro, Team Lakshya chose the GoPro Hero Surf HD.

The GoPro camera allows the user to capture videos on three different resolutions with different angle of view as per user's requirements, the resolutions being

1. 1080p: 1920×1080 True HD featuring a 127º angle of view, 30 fps, and 16:9 widescreen aspect ratio
2. 960p: 1280×960 Ultra Wide and Tall HD featuring a 170º angle of view, 30 fps, and 4:3 aspect ratio.
3. 720p: 1280×720 Ultra Wide HD featuring a 170º angle of view, both 30 and 60 fps, and 16:9 widescreen aspect ratio.

The cameras is also capable of shooting hands-free, 5 megapixel photos automatically at 2 / 5 / 10 / 30 / and 60 second intervals until the batteries die or the SD card is full (2.5 hours).

However, Team Lakshya hasn't yet started the use of image processing software, at the time of writing of this journal but intends to do before the competition and use it in the competition as Image processing forms a core part in the mission. The software that has been chosen for image processing is MATLAB. Team Lakshya has also not set up a telemetry mode of transfer of data between the camera and the ground station control but has been turning on the camera on the aircraft before take-off during a flight and obtaining the images or videos after landing of the aircraft via the SD card present in the camera. The team is yet to finalize on the mode of transfer of data and should be able to integrate it to the aircraft by the time of the competition.

Below are some of the pictures taken by Team Lakshya's aircraft.

7. MISSION PLANNING

The mission, as per the competition requires navigation of an assigned path by the built aircraft autonomously. In order to accomplish the mission successfully, Team Lakshya has developed a strategy, it is as follows

1. Report to the Ground Area
2. Obtain a briefing on the mission and analyse it
3. Designation of tasks to team members
4. Assembly of UAV components
5. Set up of Ground Station Control
6. Checking communication systems
7. Signal interference check
8. Set up and testing of Imagery system
9. Air Frame Check
10. Weather conditions check
11. Safe hasslefree take off
12. Commencement of Mission
13. Constant visual monitoring of UAV in flight
14. Assignment of waypoints to UAV through Ground Station Control
15. Maintaining constant checks on
    a. Wind
    b. Altitude
    c. Barriers around
16. Constant monitoring on battery levels
17. Commencement of Imagery when required
18. Processing of captured images
19. Completion of Navigation of assigned path autonomously
20. Weather Conditions check
21. Carry out a Safe Landing
22. **MISSION ACCOMPLISHED**

The team would have pre assigned the tasks to the members, depending on the pros and cons of the team member, in order to maximize participation. The team members are only reminded of the task after the mission briefing.

8. Failure Mode Evaluation and Analysis

Team Lakhsya's UAV was tested in various conditions and has attempted to make the aircraft a fail-safe one. Team Lakshya was able to analyse possible failures that could occur during the mission, evaluate them and has tried to overcome them by adapting some feasible and obvious solutions.

In order to understand Team Lakshya's Failure Analysis chart, and understanding of the following abbreviation terms are necessary.

1. PCFF or Possible Cause for Failure: It describes the possible cause of the failure that may occur during the mission
2. DOD or Degree of Danger: Describes the extent upto which the possible failure can affect the mission and the UAV. Two types:- C or Critical and M or Manageable.
3. MTTF or Mean time to failure: The probable amount of time between commencement of mission and occurrence of the analysed failure.
4. TLIS or Team Lakshya's Intended solution: The solution intended to be used by team lakshya.
5. WCS: Worst Case Scenario: The outcome of failure of Team Lakshya's intended solution.
6. MF: Mission Failure
7. MM: Manual Mode
8. APM: Autopilot Mode (Autonomous mode)

The following table consists of Team Lakshya's Failure analysis, respective details of each failure and possible solutions.

S.No	PCFF	DOD	MTTF	TLIS	WCS
1.	Wind Turbulence	M	NA	On Ground RC Pilot takes over	Airframe Damage leading to MF
2.	Rainfall	C	NA	On Ground RC pilot takes over and tries to land Aircraft safely.	Severe damage to aircraft electronics leading to MF

S.No	PCFF	DOD	MTTF	TLIS	WCS
3.	Loss of Telemetry Signal in MM	C	10-30 mins	Aircraft aborts flight and returns to launch	MF
4.	Loss of Telemetry Signal in APM	C	5-40mins	Aircraft aborts flight and returns to launch	MF
5.	Low Battery	M	20-40mins	Aborts flight plan and circles launch area or home at 50ft altitude until MM control is done	Mission maybe completed in MM else MF.
6.	Servo Failure	M	NA	Aircraft control changed to MM if vital servo has failed	Mission can be executed in MM.
7.	Autopilot Failure	C	NA	Aircraft control switched to MM	Mission execution In MM
8.	Propulsion Failure	C	0-40min	NA	Aircraft Crash lands and MF
9.	Imagery System Failure	C	10-40min	NA	MF

9. Conclusion

The journey towards the building of an Autonomous UAV has culminated in the following:

- An operating model of the UAV has been successfully built, tested and is all ready to be demonstrated.
- The deployment of the autopilot system and the associated software integration has been successfully accomplished.
- The project has not only attempted the incorporation of the latest techniques/ technologies, but all along adhering to the requirements of the mission, both by the specifications and in spirit.

9.1 Post Amble:

With the prospect of the demonstration being successful and matching the best in the field, if not surpassing them, we look to take the honours at the competition and look forward to being a part of the ensuing missions with awe inspiring technological marvels to surpass one and all from time to time.

10. Acknowledgements

Team Lakshya would like to thank the management and faculty at MSRIT for extending their support and assistance without which Project Lakshya would've been incomplete. The team would also like to thank AUVSI foundation for giving them this wonderful opportunity.

The team specially appreciates the contribution by the following,

1. Dr. S.V. Prakash (Project guide and Prof DEPT of MECHANICAL ENGINEERING MSRIT)
2. Kiran Kulkarni (Project guide and Project assistant DEPT of AEROSPACE IISC)
3. Dr. Prashanth.T (Project Mentor and Doctor St John's Medical Research Institute)

11. Reference

http://paparazzi.enac.fr/wiki/