ARCAA UAV Challenge - Outback Rescue 2009
Deliverable 1: Report on UAV design concept and proposed safety methodology
Team Skylight

1. Executive Summary

This document outlines Team Skylight’s approach to solving ARCAA’s UAV Challenge Outback Rescue 2009, including essential UAV design parameters and safety methodology.

Airframe design is based around an off-the-shelf RC aircraft, with a 2-cycle gasoline engine as power plant. Permanent data communication is provided by a long rage data link based on 900 MHz FHSS technology. Sensors include thermopiles for attitude determination, pressure sensors for altitude and airspeed, GPS for navigation, sonar for precise height determination during landing and takeoff and custom sensor for RPM detection. Sensor processing is done by custom circuitry, as well as actuator control, flight termination and payload release. Flight control is done by custom developed software running on an onboard Pico-ITX embedded computer.

Safety is a primary concern, and will be addressed by safety measures that include independent flight termination circuitry, system sanity monitoring, enhanced flight termination mode and safety oriented operational procedures.

2. Introduction

Team Skylight is located in Brasília, Brazil, and is comprised of two members, Eduardo Damasceno and Flávio Stutz. This is the second year we take part in the competition. In 2008 we were approved in all phases of the competition, but due to last minute problems could not attend the event.

Eduardo is a software developer by profession, and a business manager by schooling. An aviation enthusiast, Eduardo has been for years both an R/C hobbyist and a skydiver. Alongside the aviation passion, he’s been fiddling with electronics for a long time, having developed several microcontroller based devices. For him, the opportunity to design and build an UAV for the challenge was just too wonderful to pass.

Flávio is also a software developer by profession, but a physicist by schooling. Sharing the same passion for challenge, Flávio grew interested in the possibility of applying both his knowledge of physics and software development on the tricky task of developing an autonomous flying machine, capable of finding and rescuing a lost person in distress. As he dove into the world of real-time software development, machine vision, control theory and aeronautical engineering, his interest and admiration for the challenges involved grew stronger.

The team has been working towards the UAV outback challenge since mid 2007. The approach chosen for solving the challenge is largely based on the concepts of incremental and iterative development, by tackling the larger risks first and building testable, functional parts in small increments. Based on the progress so far, the team is confident on their capacity to achieve the proposed goals.

3. Concept Overview

Airframe and avionics

The airframe selected for the mission is based on a commercial, off-the-shelf R/C plane, Sigs Rascal 110. The Rascal 110 was chosen as a platform for development due to its low cost, flight characteristics and its capacity for the required payload. The most relevant characteristics of the airframe are:

- High wing design with some dihedral (increased positive stability)
- Flat bottom, tapered airfoil with large surface area (better efficiency and lift)
- Large scale (better lift-to-drag ratio due to Reynolds number effects)
- Streamlined fuselage (lower parasitic drag)

These characteristics amount to a more stable airframe, decreasing the demands on the autonomous control systems; to the capacity to carry a greater payload without excessively increasing the wing loading and maintaining good climb rate; and to a fast aircraft, aiding in meeting the time constraint of the search and rescue challenge.

The chosen power plant is the Fuji Imvac BT24 gasoline engine, due to cost and reliability. The engine has been further modified for increased fuel efficiency by careful selection of carburetor and propeller. Magneto ignition was chosen for it’s reliability, autonomy and lower EMI generation. Extra measures were taken to avoid EMI, including total electrical isolation of the ignition control circuitry via optical fiber.

The chosen airframe/power plant configuration results in an aircraft capable of flying in excess of 60 knots, while still keeping safe stall/take off/landing speeds, due to the reasonable wing loading (calculated in around 30 oz/sq. ft. with avionics, fuel for one hour of flying and payload).

Flight actuators are 5 R/C servos, including 4 high torque digital servos and one standard servo. Individual aileron servos enable the use of flaperons, decreasing necessary landing speeds.

Servos are controlled by a custom designed circuitry, based on Freescale’s MC68HC908AP32 microcontroller. This device receives command inputs from the control computer and decodes incoming PWM signal from the 2.4 GHz radio receiver, switching between the two under operator control. This device has an independent processor and activates the flight termination mode upon absence of heartbeat from the control computer, or upon explicit termination command.

Sensor Processing

The sensor array installed on the aircraft is comprised of the following elements:

- Static pressure sensor for barometric altitude and climb rate calculation (MPXA6115A)
- Differential pressure sensor for airspeed calculation (MPXV7002)
- 6 IR thermopiles for attitude determination (FMA co pilot sensor module / vertical z sensor)
- 5 Hz GPS receiver for navigation and ground speed determination (Globaltop G33)
- Ultrasonic range finder for precise height determination during landing and takeoff

With the exception of the GPS receiver, all sensors will be interfaced with custom designed circuitry, also developed around Freescale’s 68HC908AP32 microcontroller. Apart from the static pressure sensor, all analog sensors will be digitally sampled by the 10 bit integrated ADC in the microcontroller. Due to the necessary higher resolution, the static pressure sensor is externally sampled by a Sigma Delta 16 bit I2C ADC.

GPS information is received by the control computer directly from the GPS receiver via Bluetooth link, using the NMEA-183 protocol. The selected receiver provides 5 samples per second, making it suitable for use with control loops in a dynamic system.

All analog sensor information is filtered using a combination of analog filter networks, digital averaging, and/or linear regression.

Electric power will be provided by a regulated power source. Main processing unit, sensors, sensor processing circuitry, radio receiver, servos and payload system are operated by a high power LiPo battery pack through a high efficiency, low noise regulator. The GPS receiver has an individual battery and is capable of operating for a much longer period than necessary for mission completion.

All flight termination circuitry is operated by a separate battery to ensure proper execution of flight termination mode in case of failure of any other system. Please check section 4 – Safety and Flight Termination.

Control, navigation and autonomy

The control computer is designed around VIA's EPIA PX5000G, due to its very small size, ultra low power consumption, solid state nature and increased system stability. The most relevant characteristics of this device are:

- 500 MHz VIA Eden ULV processor
- Solid state, fanless design
- Up to 1GB DDR2 support
- 4 USB ports
- 1 RS-232 port
- Pico-ITX form factor (10 x 7.2 cm)

All control and navigation software is custom designed and implemented in Java. The software was designed with very careful attention and applying best practices for ensuring predictable execution time, necessary for real-time behavior.

Control is implemented with PID control loops using environment feedback from the sensors and actuating on the aircrafts control surfaces. Navigation is GPS based.

Visual identification of the target will be primarily done by a human operator, while possibly assisted by using machine vision for shape identification. A CCD camera with zoom capabilities and sensible to the far infrared spectrum (Sony FCBEX78BP) will be used with visible light filters to capture image below the airplane. This configuration is based on the assumption that the exact same specified IR illuminator will be pointed skywards above the target during the challenge.

The team aims for the highest degree of autonomy, including take-off, navigation, target acquisition, payload delivery and landing. Final status on achieved autonomy will be reported in the next deliverables. In order to increase quality and safety, simulations are being conducted with hardware-in-the-loop setups, using Laminar Research's X-Plane flight simulator.

Data communications

Basic line-of-sight control is provided by a 2.4 GHz unidirectional radio link, using an off-the-shelf R/C transmitter and R/C receiver. This data communication link is used for manual override control, intended for emergencies or situations in which full autonomy is not possible.

Permanent and bidirectional data communication is provided by an onboard Laird Technologies' AC4790 based radio modem, working with FHSS technology on the 900MHz ISM band under FCC part 15.247 regulations.

During all phases of the mission the permanent data link is expected to provide aircraft state information to the ground control station and receive mission commands, including flight termination, mission abortion and target confirmation. Experiments have shown that the chosen infrastructure provides very low latency, and that the necessary range is easily accomplished (setup is rated 40 miles LOS).

Video feed for target identification is provided by an additional radio link, using an onboard camera (Sony FCBEX78BP) and an A/V radio transmitter operating in the 2.4 GHz ISM band. Since the transmitter shares the 2.4 GHz band with the R/C radio, video transmission is enabled only once the aircraft is off manual control and on fully autonomous mode, beyond R/C radio range.

Ground control system

Essential ground control system is comprised of an R/C transmitter, a notebook computer, radio modem, A/V radio receiver, antennas and custom designed software. All analog A/V signal is digitally sampled and recorded.

The ground control station software is developed in Java, and provides the following functionality:

- Data communication link control and monitoring
- Flight state information (KTIAS, propeller RPM, vertical speed, latitude, longitude and altitude, plane attitude)
- Aircraft systems health information (batteries voltage monitoring, available fuel, engine health)
- Mission state control (current mission state, mission update, mission abortion, flight termination, target confirmation)

Payload and payload delivery system

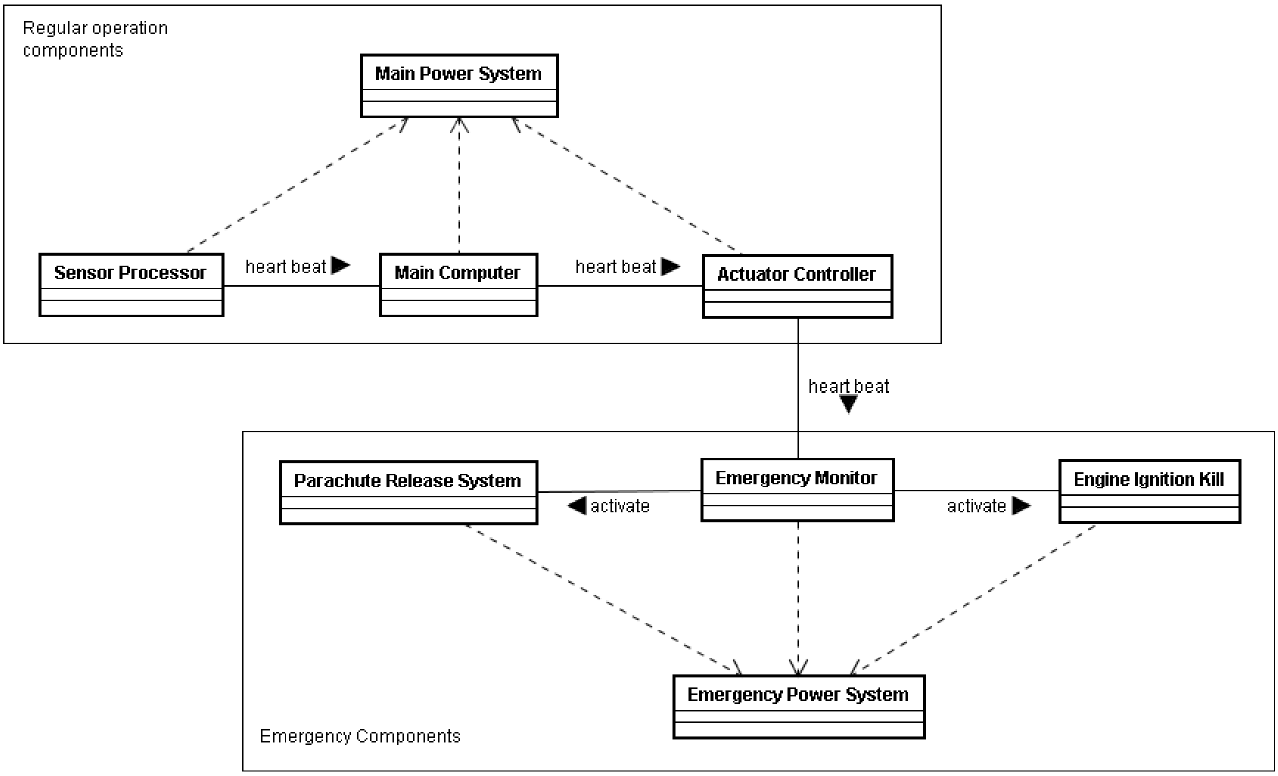
The chosen payload, based on the specified challenge rules, will be a 500 ml bottle of water suitable for drinking. It will be attached to a small round parachute, which will provide a slower descent to the ground.

Payload is attached near to the planes center of gravity, to avoid its dislocation after payload release. Attachment will be provided by single point release system, made of monofilament nylon line, similar to fishing line, of sufficient tensional strength. The release device was custom developed, and consists of nichrome wire attached to the single point release line, that once activated becomes incandescent and immediately melts the nylon line, releasing the payload. Tests proved the system to be very effective.

4. Safety and Flight Termination

Safety will be provided by a combination of operational procedures, emergency procedures, system monitoring and a flight termination system. The proposed flight termination system is outlined next.

Each node in the execution chain is responsible for monitoring the previous node for a heart beat, and in case of detected failure cease its own heart beat. This ensures that any malfunctioning link in the chain causes the flight termination mode to be activated. Flight termination can also be activated from the ground station.



The flight termination mode consists of killing the engine ignition and activating the added safety measure of a parachute, meant to decrease the kinetic energy of the system and further decrease the chance of property damage and human harm.

The parachute system consists of a parachute cluster of 3 round pull-down apex parachutes, made of low porosity parachute fabric and a parachute deployment system. As per the challenge rules, the expected drifted in a worst case scenario was calculated and is presented below:

Airplane true airspeed: 30.87 m/s (maximum aircraft speed)
Wind speed: 12.86 m/s (25 KTS, maximum allowed wind speed for takeoff)
Airplane altitude: 121.91 m (400 ft ceiling)
Aircraft descent rate under parachute: 6.7 m/s (found experimentally)
Time to touchdown: 18.19 seconds
Airplane ground speed: 43.73 m/s

Horizontal drift: 795.76 meters beyond boundary.

Parameters that will be monitored to improve safety during flight include fuel autonomy, battery voltages and data communication link quality.

The following operational procedures have been outlined to increase safety and efficiency during mission execution:

- Aircraft pre-flight check
- Aircraft refueling
- Ground systems pre-flight check
- Take-off

- In-flight
- Landing
- Emergency

5. Insurance, budget and funding

Insurance for public liability is a safety concern which we address in the following manner:

- All flight tests are conducted by a COBRA (Brazil's FAI affiliated aero modeling association) affiliated pilot, and thus are covered by a R$ 100,000.00 public liability insurance (equivalent to about US$ 60,000.00)
- Specific insurance that is valid in Australia will be purchased for the days of the event

Necessary hardware budget for the challenge was calculated in US$ 4675.00. That includes airframe, power plant, radio systems, avionics and ground station components. It does not include cost of labor, software, travel expenses and others indirect costs in attending the challenge. As of now, the entire project has been funded by the team.