ARCAA UAV Outback Challenge 2010 – Search and Rescue
Deliverable 1: Flight Safety Review
Team Skylight

1. Introduction

This document outlines Team Skylight's approach to solving ARCAA's UAV Outback Challenge 2010 – Search and Rescue and outlines 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. Environment sensing is accomplished with MEMS gyroscopes, accelerometers and magnetometer for attitude determination, pressure sensors for altitude and airspeed and GPS for navigation and ground speed. System state is also monitored, including engine RPM, cylinder head temperature and power supply levels.

Sensor processing is done by custom hardware and software, as well as actuation control, flight termination and payload release. Flight control is done by custom developed software running on an integrated Gumstix Overo Computer-On-Module.

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

2. Overall Design of the UAV System

Airframe and avionics

The airframe selected for the mission is based on a commercial, off-the-shelf R/C plane, Sig's 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 reasonably fast aircraft, aiding in meeting the time constraint of the search and rescue challenge.

The chosen power plant is the 3W-24i 2 cycle gasoline engine, due to its reliability and power-to-weight ratio. The engine has been further modified for increased fuel efficiency by careful selection of carburetor, propeller and exhaust system. The engine works with electronic ignition, so extra measures were taken to avoid EMI.

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 one of three sources, switched by an internal multiplexer:

- an external 2.4 GHz RC receiver when under manual control
- an internal and independent flight termination system when terminating flight
- the main onboard computer while in autonomous mode

Additional details are presented in the Safety and Flight Termination section.

Sensor Processing

The set of sensors installed on the aircraft is comprised of the following elements, all integrated in a custom designed board:

- Static pressure sensor for barometric altitude and climb rate calculation (BMP085)
- Differential pressure sensor for airspeed calculation (MPXV5004DP)
- 3 axis gyroscope, 3 axis accelerometer and 3 axis magnetometer for attitude determination
- 10 Hz L1 GPS receiver for navigation and ground speed determination
- Temperature sensor for cylinder head temperature measurement (LM34)

All sensors will be interfaced with custom designed circuitry, developed around Parallax´s Propeller multi-core microcontroller. All analog sensors will be interfaced with a 12 bit SPI ADC, while all digital sensors are interfaced via an I2C bus.

Raw GPS information is passed on to the onboard CoM for processing and solution calculation. The current architecture supports RTK based DGPS for precise navigation, take-off and landing. DGPS corrections are relayed from the GCS/VSM.

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.

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 on Safety and Flight Termination.

Control, navigation and autonomy

The control system is supported by a Gumstix Overo Computer-on-Module, chosen due to its very small dimensions and weight, very low power, robustness and maturity. The most relevant characteristics of this device are:

- 600 MHz ARM Cortex™ A8 Core with hardware floating point, NEON technology and VFPv3 architecture
- Integrated 256MB RAM & 256 MB Flash POP memory
- Very low weight (6 grams)
- Very small dimensions (17mm x 58mm x 4.2mm)
- Very low power consumption (under 1W)
- Linux / OpenEmbedded based
- Many interfacing options
- Solid state, no fan or other moving parts
- Vibration tested (MIL-STD-810F 514.5)

All control and navigation software is custom designed and implemented in Java. The software was designed with very careful attention, testing 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, possibly 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

The architecture of our UCS is based on STANAG 4586. Although it doesn't yet implement all messages covered by the specification, all capabilities created for the challenge were based on it.

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. A second notebook will be used for ground station contingency.

There are three main components in UCS:

- HCI (Human Computer Interface): provides operator display and input tools for the various types of activities needed for UAV operation
- Core UCS: Provides services to HCI such as messaging, storage, monitoring and mission validation
- Skylight VSM (Vehicle Specific Module): Responsible for authorizing specific ground stations to control the vehicle. It routes messages from the local network ground stations to the vehicle by converting UDP packets to/from a custom messaging protocol used by the VSM<->Vehicle wireless link. The conversion of analog video signals to

streamed media over the local network is also performed by the VSM. It´s possible to have multiple computers on a local network controlling the vehicle, all receiving data and video without any performance degradation.

The ground control station software is developed in Java and provides functionalities such as:

- Vehicle control management and link monitoring
- Flight state information (IAS, propeller RPM, latitude, longitude, altitude, plane attitude etc)
- Vehicle systems health information (batteries, fuel, software status, communication link, GPS quality etc)
- Vehicle flight path mode control (Waypoint Director, Loiter Director, Communication Hold, GPS Hold, Safety Procedures, Flight Termination etc)
- Mission control (Mission creation,start/stop, manual control override, authorized mission boundaries, safety actions on adverse situations etc)
- Operator utilities (visual/audible timer, operator annotation tool, log playback etc)
- Skylight specific vehicle configuration (advanced PID adjustments, internal autopilot parameters, surface control monitoring)
- Extensible plugin architecture at software level

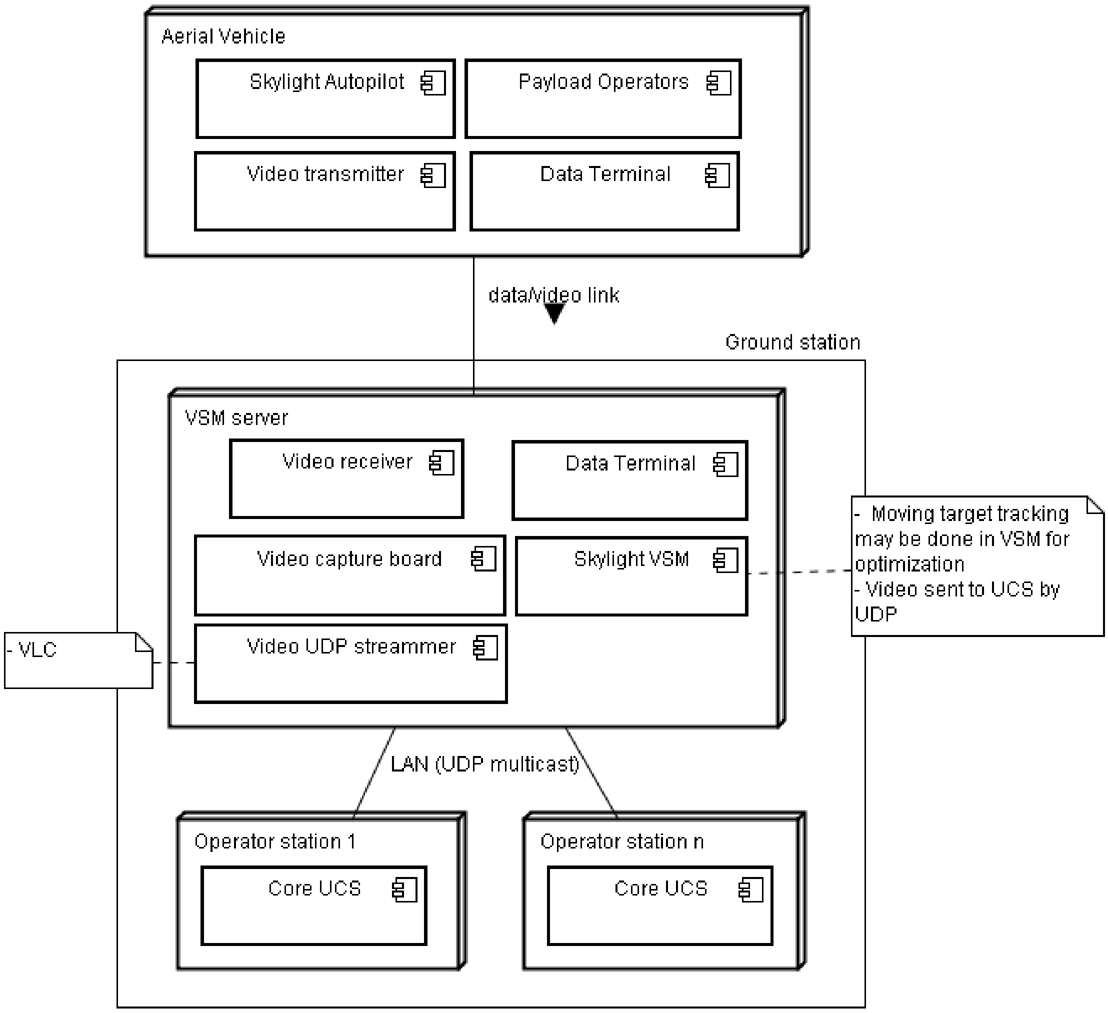


Figura 1 - Diagram showing some of the UCS components

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.

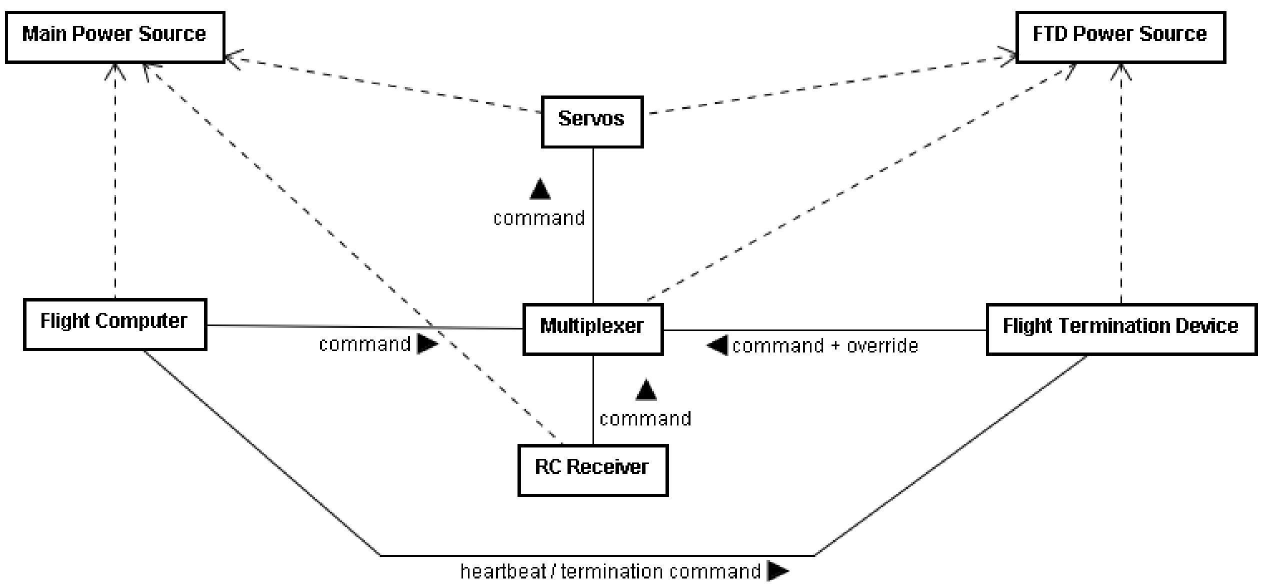
Payload is attached near to the planes center of gravity, to avoid its dislocation after payload release. Attachment will be provided by single point release system, made of monofilament nylon line, similar to fishing line, of sufficient tensional strength. The release device was custom developed, and 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.

2. 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.

As represented in the image, there is an independent flight termination device, with its own power source and processor, capable of overriding the flight computer and commanding the servos to a flight termination configuration.

Flight Termination System Overview



Flight termination shall occur if either:

A. The Flight Termination Device does not receive a heart beat from the Flight Computer at a minimum rate of 1 Hz
B. Flight Computer commands Flight Termination Device to initiate termination immediately

Situation A will occur exclusively in case of autopilot failure, either by software failure or hardware failure. At all times the Flight Computer shall heartbeat the Flight Termination Device.

Situation B will occur in either of the following cases:

- Autopilot detects mission boundary crossing
- Autopilot detects simultaneous loss of data link and GPS signal
- Autopilot detects loss of data link, enters Data Link Loss Flight Mode, does not reestablishes communication and loiters around Airfield Home waypoint for 2 minutes without manual RC override for landing
- Autopilot detects loss of GPS signal, enters GPS Signal Loss Flight Mode, does not reestablishes GPS signal, is manually navigated back to field via onboard video, loiters around Airfield Home waypoint for 2 minutes without manual RC override for landing
- GCS operator requests flight termination

Furthermore, in case of engine failure detection by the autopilot the autopilot shall initiate a controlled crash landing maneuver. The maneuver consists in spiraling down to ground level in a shallow angle, in order to avoid excessive airspeed and kinetic energy, which decreases the chance of inflicting harm or damage, all while still reporting its position back to GCS.