University of Arizona
Deliverable 1

UAV Outback Challenge 2016

Summary

The UofA 2016 Outback Challenge Team's approach maximizes safety by minimizing complexity, using only one tightly integrated platform in order to complete the mission. The Flight Platform will have a high degree of autonomy, with the main role of the ground station being to monitor the health of the aircraft and its progress in the mission, only intervening when mutable matches for Joe are found.

We chose a Gas powered Helicopter because it best met the challenging combination of long endurance high weight capacity and fast forward flight, while allowing for a single aircraft to be used to complete the mission, reducing the complexity and increasing safety for the mission.

1) Overall design of UAS systems

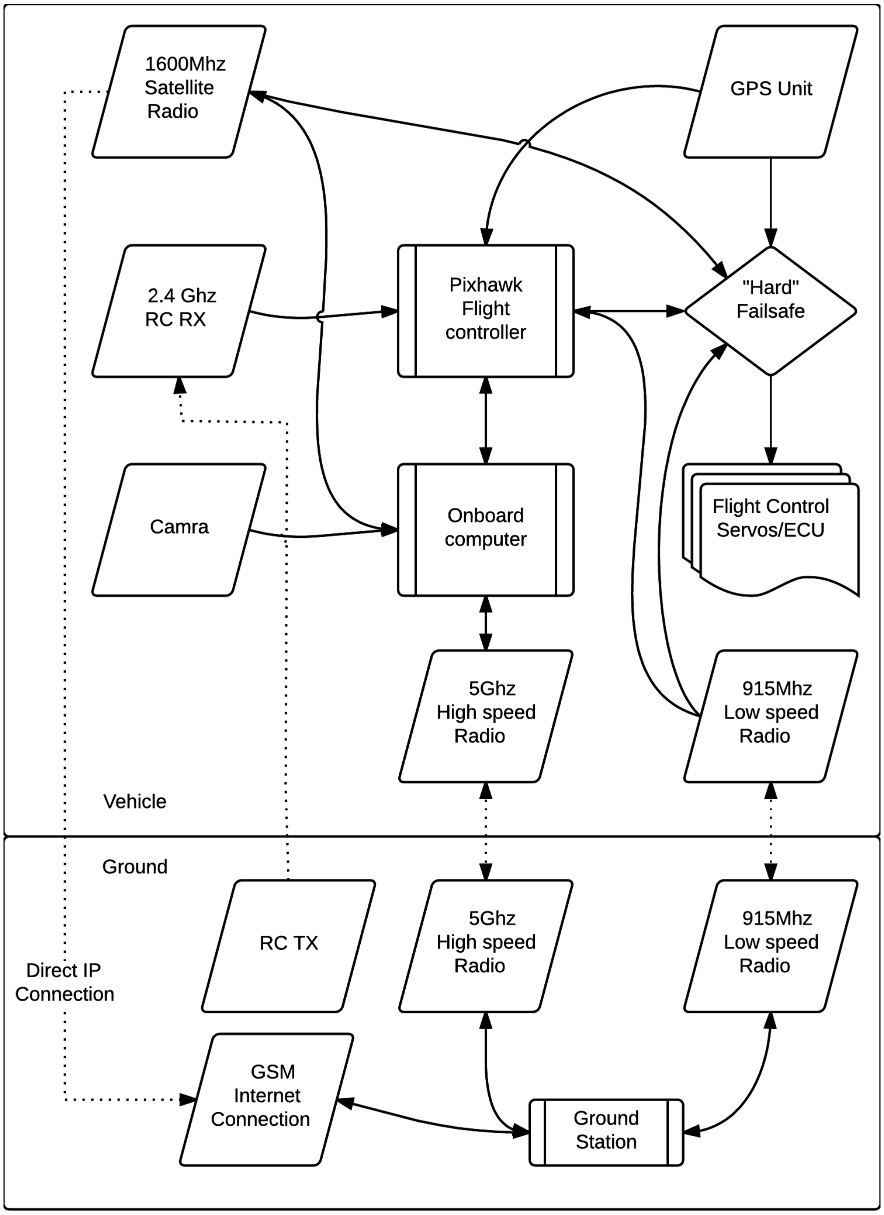
Pixhawk Flight controller – Flight controller will be the open source Pixhawk flight controller running a custom version of the APM:Copter Firmware. The primary link for this flight controller will be via the low bandwidth 915Mhz link, using the MAVlink (Micro Air Vehicle Communication Protocol) the Pixhawk will also be capable of using the 5Ghz High bandwidth link, or the Very Low bandwidth 1600Mhz Satellite connection via the onboard computer, as a last resort backup.

Onboard Computer – A NVIDIA K1 based onboard computer will provide camera image analysis, data monitoring and switchover (In the event of a loss of a communication method). Its primary link will be over the high bandwidth 5 GHz link to the ground station, and as backups it will utilize the 915 MHz radio link for low bandwidth communication, and will automatically send only high priority status and error messages over the Very Low bandwidth 1600 MHz Satellite connection

Camera – A single stereo camera for acquiring and ranging Joe. It will be connected to the onboard computer over USB.

RC Control – The RC Link will be a 2.4 GHz Spektrum RC Control Link. This link will be utilized to take control of the Model in the event of a failure of some kind while in Line of Sight. In order to comply with Section 7.5, we will be operating under the Radio-Control class license in compliance with section 7.5.

Ground Control Station – Will consist of a network of computers displaying all available telemetry from the craft including Key data to both the team and the organizers, it will connect directly to the High, and Low bandwidth links and indirectly (Via a GSM Internet connection) to the Ultra-Low Bandwidth Link (per sections 3.2.2, 3.3.1-3.3.3.) The ground station will also have a prominent Emergency stop button that automatically overrides any signals and sends the Flight Termination commands to the aircraft over the High, Low and Ultra Low Bandwidth Links.



"Hard" Failsafe system – The hard failsafe system will determine based on independent data from the GPS when the craft has breached a "Hard" failsafe boundary as set forth in 3.1.3. All Control signals (PWM signals to servos and ECU) pass through the "Hard" Failsafe witch has the ability to in hardware using logic level relays disconnect the Flight controller from the outputs and connect them to the Failsafe's board for override signals. The "Hard" failsafe system will have separate power system (Battery Voltage regulators ect…) The failsafe system will monitor heartbeat messages at a rate of 10Hz from the FC and in the event of 5 consecutive lost heartbeat signals the "Hard" Failsafe system will activate. (Flight Termination per 3.1.4) In the event of a loss of power to the "Hard" failsafe system the relays will return to being connected to the FC to provide an additional level of redundancy. The "Hard" failsafe controller has triple redundant remote activation methods it independently monitors the Low and Ultra Low Bandwidth links inspecting for a failsafe packet and should a failsafe packet be received over the High bandwidth link the Pixhawk can relay that message to the "Hard" Failsafe. This system works as a last resort with the Flight controller implementing a "Soft" Failsafe if it determines the craft could possibly breach the hard boundary's, bringing the craft down in a controlled manner as opposed to the hard landing the "Hard" failsafe will cause.

High Bandwidth Link – The High Bandwidth link will be composed of a Ubiquity Rocket 5Ghz radio that is capable of utilizing 5.19 GHz (Channel 36) to 5.825 GHz (Channel 165). This link will be connected directly over Ethernet to the Main Computer in order to facilitate high speed communication. In order to avoid

Radar channels and to have the ability to use the maximum allowed EIRP (4W) per Class 2000 License Item 45B, we will be utilizing channels 149-165, 5.745 GHz to 5.825 GHz. In order to comply with Section 7.5, we will be operating under the other devices category of the low interference potential devices (LIPD) class license in compliance with section 7.5.

Low Bandwidth Link – The Low Bandwidth Link will be composed of a RFD900+ radio model operating at 902 – 928 MHz. The serial receive lines on the radio will be split and connected to both the “Hard” Failsafe and the Pixhawk. In order to comply with Section 7.5, we will be operating under the spread spectrum devices category of the low interference potential devices (LIPD) class license

Ultra Low Bandwidth Link – The Ultra-Low Bandwidth Link is a last resort backup link operating on the 1.616 to 1.6265 GHz Band to the Iridium Satellite Network. The ground station will connect directly to the aircraft using a GSM IP connection. In order to comply with Section 7.5, we will be operating under the spread spectrum devices category of the low interference potential devices (LIPD) class license in compliance with section 7.5.

a) The preliminary design of the flight termination system

The flight termination system will consist of 2 layers

- The “Hard” Flight Termination System (per section 3.1.5)
  - Implemented by both the standalone "Hard" Failsafe system and the Flight Controller
  - Consists of closing the throttle and adjusting the pitch of the blades to maximum Negative pitch to allow them to spin and gain rotational inertia in order to slow the fall somewhat and keep the Model from tumbling potentially causing more harm and closing the throttle to deactivate the Engine (called “Bailout”)
  - The GPS is passed though in hardware to both the Flight controller and the standalone "Hard" Failsafe system, in order to facilitate redundancy
  - Maximum distance the helicopter can travel after activation of the “Hard” Flight termination system is calculated as follows, with a maximum initial speed of 166.3 km/h (120km/h+25knots) once the flight termination system is activated it will increase the C_D to around 1.2 (Johnson, 1980) and at the maximum all up weight the craft would take 13.553 seconds and travel a distance of 24.75m. Given this a 100m buffer zone away from the flight corridor edges is more than adequate to provide safety.
- The “Soft” Flight Termination System
  - Implemented in the Flight controller only
  - Provides course corrections to avert an activation of the hard flight termination system
  - Can land the craft safely (as opposed to coming down hard potentially damaging property or the vehicle)

b) The preliminary design of the Geofence System

- The Geofence system will operate as an integral part of the flight termination system as noted in the above section

- Position of the craft will be determined by one GPS utilizing Real Time Kinematic solver to augment GPS position allowing solving of the position to within ~10cm providing a high degree of accuracy.
- The Geofence will be programmed into both the Flight controller and the “Hard” Failsafe system before the start of the mission and be validated by automated and manual checks.

2. Description of how the UAVs will be employed to complete the Mission

Figure 1 - Bergen RC Industrial Twin

- The mission will be completed solely with a single craft, a Bergen RC Industrial Twin (Figure 1) loaded with the necessary electronic hardware to complete the mission.
- The aircraft will fully comply with all requirements laid out in sections 3.1.1

  Industrial Twin (Bergen, 2015):
  - Gas powered RC Helicopter (Rotary Wing)
  - Utilizing 890mm rotor blades (rotor diameter ~1.8m)
  - Lift capacity ~12Kg (depends on configuration)
  - Dry weight 8.1kg
  - Max Takeoff weight 19.5kg
  - Maximum fuel consumption 32.5 mL/min (with a fuel density of 726 g/L we will carry around 2.437 L of fuel or 1.769 kg in crash restraint tanks, in order to have a minimum flight duration of at least 75 minutes 60 minutes of normal flight and 15 minutes of reserve fuel)
  - Cruising altitude 400ft AGL (If experiments show a significant improvement at 400-1500ft AGL then we will apply for permission and will adjust the mission accordingly.)
  - Will have external High visibility lights on both sides and on the underside to indicate flight mode/armed state
- Phases of the mission:
  1. Takeoff Autonomously under the observation of the Pilot.
  2. Fly the course at a target speed of 120km/h (in order to allocate the maximum amount of time to searching for Joe and retrieving the sample from him.
  3. Search the search area as quickly as possible using machine vision to identify potential targets and sent them back over the high speed link to the Base Station for review and identification. If required, make low passes at ~50m to gain more accurate imagery and make a better determination as to whether the object is Outback Joe.
  4. After identifying Outback Joe, land 50m away, switch to backup satellite communication when below the horizon, and shut down the engine.
  5. After Outback Joe inserts the sample capsule and depresses the button, after 60 seconds the engine starts up and the Vehicle takes off.
  6. The Vehicle flies back to the Ground station Landing Zone, and lands autonomously under the supervision of the Pilot.

3. Risk Assessment

Risk assessment matrix

Risk Assessment	Risk Mitigation
Insurance	Development will be carried out at the local AMA field, under AMA insurance and rules. Over the next year we will investigate insurance for flying in Australia
Flight Operations	Flight operations will be carried out in accordance with AMA Guidelines for safe flight, and in accordance with safety and pre-flight checklists to be created.
	Flights to be carried out at AMA approved airfields, with full length autonomous flights to be carried out at designated sites minimizing the potential to damage property and people in the event of a failure of the craft.
	Main electrical power will be provided by dual redundant diode isolated LiPo batteries, with a dedicated backup provided for the Hard Flight Termination system
Ground Operations	Fuel will be stored in designated containers while on the ground, and in burst restraint safety containers while onboard the aircraft.
	Engine will be started in accordance to AMA guidelines with an electric starter, from at least 20m away.
Assembly	Assembly of the airframe will be done by the manufacturer to ensure correctness, and will be checked by an experienced Helicopter pilot regularly, additionally, all repairs will be undertaken by the pilot and checked by other experienced personnel.
	All electrical wiring and connections will be made to NASA (National Aeronautics and Space Administration) Standards (NASA-STD 8739.4) by experienced personal and checked by another to ensure maximum reliability.
Autopilot and Hard Failsafe	The autopilot will undergo extensive reliability testing and qualification, with changes made as necessary to the software to maintain this.
	The Hard Failsafe will undergo extensive testing and design review to ensure it has a MTTF (Mean time to failure) of at least 250,000 hours allowing for a less than .0004% chance of failure during any given period, with the flight controller implementing the same functions as the Flight Termination system to increase the MTTF further.
	The autopilot will send a 10 Hz Heartbeat to the Hard Flight Termination system and if it does not receive these for 10 consecutive heartbeats it will Bailout to protect the craft and bystanders
Air traffic	All flights will be carried out under 400ft AGL at AMA approved airfields, mitigating the possibility of any air traffic interaction, long range flight tests will also be carried out under 400ft AGL, and the local air traffic controllers will be notified of our presence
Aircraft Fly away	Will be mitigated by both the auto pilot and Hard Flight Termination system simultaneously monitoring the GPS position and both capable of commanding a flight termination, as well as the Ground station
Software	Software will be rigorously tested both using both automated SIL (Software in the loop) and manual SIL and HIL (Hardware in the loop) testing
	We will use best practice industry standards for software version control and deployment, as well as configuration management. With verification of configuration and software versions as part of the pre-flight procedures
Air traffic	An ADSB receiver at the ground station will monitor air traffic. If air traffic is scene in the area will command the UAV to return to base, soft termination, or hard termination based upon range safety.
High winds	Flight tests will be conducted to determine the maximum safe operating winds, should the weather instrumentation at the Ground Station exceed these limits flight termination will be commanded
Pyrotechnic	Will not be utilized as per 3.4.5

systems	

a) The proposed strategies in response to failures such as loss of data link, loss of GPS and loss of engine power

Hard Failsafe	Soft Failsafe	Condition/Conditions
	Auto rotation	Engine Failure, The model will have an engine monitoring system if it has a failure of any kind it will be shut down, if the Model is in visual range the pilot will be able to attempt Autorotation
	Land	Loss of GPS position, for more than 30 seconds, If last known position more than 100m away from hard failsafe boundary
Bailout		Loss of GPS position, for more than 10 seconds, If last known position less than 100m away from hard failsafe boundary
	Fly back on course	Geo-Fence, if the model breaches the “Soft” Geo-Fence
Bailout		Geo-Fence, if the model breaches the “Hard” Geo-Fence
Fallback to Low bandwidth Link		Loss of High bandwidth link (10 seconds of no response to heartbeat packets)
Fallback to Ultra-Low bandwidth link		Loss of both High and Low bandwidth link (10 seconds of no response to heartbeat packets)
Proceed to the loss of communication waypoint		Loss of all communication links (10 seconds of no response interfaces except the Ultra-low speed link, no response for 1 minute on ultra-low speed link) for up to 2 minutes
Go to home waypoint for manual landing		Loss of all communication links (10 seconds of no response interfaces except the Ultra-low speed link, no response for 1 minute on ultra-low speed link) for more than 2 minutes
Land at home		No RC commands for two minutes and no communication for 2 minutes
Bailout		Aircraft in manual mode with no connection to the transmitter
Pilot manually aborts takeoff		Failed takeoff
Pilot manually lands		Failed landing at Base Station, or Return to Home activated
Return to Home		Critical unrecoverable hardware/software failure of ground station
Bailout		Autopilot lock up (as monitored by a loss of heartbeat from the Flight controller)

References

Bergen, C. (2015, 8 28). *Industrial Twin*. Retrieved from Bergen R/C: http://bergenrc.com/Twin.php

Johnson, W. (1980). *Helicopter theory.* Mineola: Courier Dover Publications. Retrieved 8 28, 2015