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Beyond line of sight control of small unmanned aerial vehicles using a synthetic environment to augment first person video

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Abstract

This paper is a summary of efforts to develop alternative methods to control small Unmanned Aerial Vehicles (UAV)† in manual mode while at Beyond Line of Sight (BLOS) range. While it is true that the majority of the UAV airborne activities will be in autonomous mode (i.e. using an autopilot) this may not always be the case, especially if there is a failure of the autopilot or need for an emergency manual override maneuver. This requirement for an emergency manual back-up mode during all flight stages remains in proposed UAV regulations being defined in the U.S., Canada and Europe. This paper proposes a possible manual pilot console using a combination of an extended-range First Person View (FPV) video augmented by a synthetic simulation environment. Practical field testing of the various elements which make up this system is presented.

Keywords: Unmanned Aerial Vehicles (UAV); Beyond Line of Sight (BLOS); First-Person Video (FPV)

1. Introduction

Although the majority of the operation of UAVs is expected to be under autonomous control by an autopilot (AP), there remains the requirement for an External Pilot (EP) who is vigilant and prepared to take manual control during all stages of flight. All Special Flight Operation Certificates (SFOC) obtained to date by our research team

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† Small UAVs are classified as under 25 kg according to recent Transport Canada guidelines for UAVs [1].

have required the presence of such a EP for each and every airborne UAV[2], and similar rules and regulations are in place or under development in both the U.S. [3] and Europe [4].

Providing an effective manual override capability at all stages of UAV operations is a challenge, especially at Beyond Line of Sight (BLOS) range or in non-visual flying conditions. If Radio Control (R/C) using un-assisted third-person vision is the only method used, effective manual control is limited to at most 1 km and only then in visual daylight weather conditions. The suitability of R/C flying methods have also been questioned from a safety as well as personnel limitation stand-point [5]. It is clear that some type of augmented control is needed to provide effective manual control of the small UAV at all operational ranges.

Since 2005 the RAVEN II research group at Memorial University has been experimenting with technologies and operational methods with the aim to improve the reliability and safety of small UAVs when flown at beyond line-of-sight (BLOS) range. These efforts have included:

- The use of First-Person Video (FPV) to improve the controllability of small UAV airframes;
- Extended range video links to allow manual override control beyond normal visual range; and,
- Using a synthetic environment as a visual enhancement at BLOS ranges or otherwise when real-time high quality video is not available.

This paper will provide a summary of these efforts to date. It should be noted that while FPV might improve situational awareness of the manual, it is not recognized in current regulations as a means to provide the detect sense and avoid function [6]. The manual control methods proposed here are solely as an emergency override, for example to permit a safe return to base maneuver following an autopilot failure.

| Nomenclature	
ADS-B	Automatic Dependent Surveillance Broadcast
AIS	Automatic Identification System (ship/marine transponders)
AP	Autopilot
ATC	Air Traffic Control
AVO	Air Vehicle Operator
BLOS	Beyond Line of Sight
COA	Certificate of Authorization
EP	External Pilot, Also Manual Pilot (MP)
FAA	Federal Aviation Administration
FDM	Flight Dynamic Model
FG	FlightGear
FPV	First Person Video
GCS	Ground Control Station
HUD	Heads-Up Display
ILS	Instrument Landing System
OSD	On-Screen Display (another name for a HUD)
R/C	Radio Control
SFOC	Special Flight Operation Certificate (Canadian equivalent of COA)
SM	Statute Mile (i.e. 1.609km)
TCAS	Traffic Collision Avoidance System
UAV	Unmanned Aerial Vehicle
VR	Virtual Reality (earlier term for FPV)

a

b
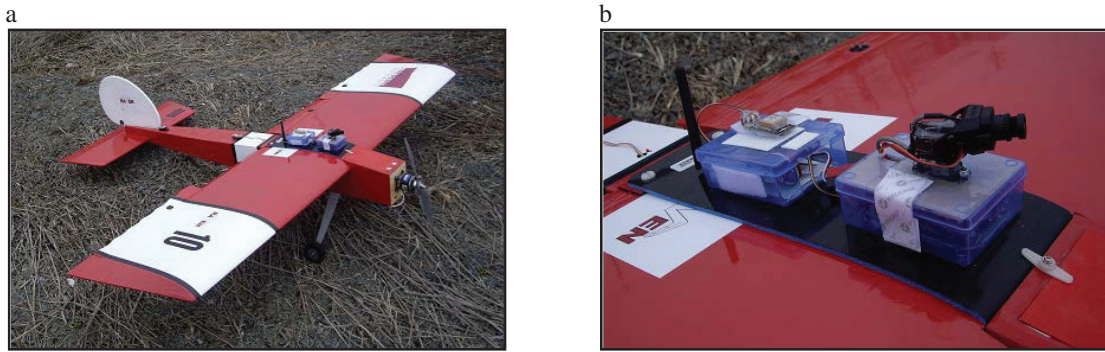
Fig. 1. (a) GianStik Test Vehicle; (b) Close-up of FPV Setup.

2. Extended range first-person video

2.1. First-person video equipment

An extended range version of the First-Person Video (FPV) setup used for a VR landing experiment (c.f. Paper 155) was developed for use during a BLOS mission. This FPV system was based on the EagleTree series of FPV products. Aimed at the high-end R/C hobby community, these components are borderline UAV avionics sets, including built-in GPS, On-Screen Displays (OSD), and a rudimentary autopilot-capability [7]. The airborne system is based on an integrated high-resolution camera integrated into a two-axis turret, and a 5.8 Ghz transmitter. The airborne components of the FPV system were integrated into a small electronics payload and installed on top of the main wing of the GiantStik vehicle as shown in Figure 1.

The FPV system was upgraded by using a high-power 5.8 GHz transmitter (i.e. 600 mW power, three times the power used in the VR Experiment). A high-gain antenna suitable for 5.8 GHz was also used, mounted on top of a 30' tall radio mast. A second hi-gain antenna suitable for the 900 MHz autopilot telemetry link was also mounted on the mast. A diversity radio-frequency (RF) switching system was used to switch between the high-gain antenna and the one built-in to the FPV goggles, depending on the strength of the signal received by both. The manual control override system built-in to the Ardupilot system could have been used to override the autopilot at BLOS range and fly the aircraft based on the FPV video. However, this was not tested during this initial BLOS mission.

2.2. Extended video during BLOS mission

The BLOS mission was noteworthy as it was the first time an SFOC was granted to the research team to fly at ranges well beyond visual range (i.e. typically a maximum range of 1 km) location). To allow this, Transport Canada would block off a section of airspace north of the abandoned U.S. Naval airbase in Argentia, Newfoundland, and temporarily classify it as restricted Class F airspace. In addition, we had to equip the UAV with the extended range video setup described in the previous section, and an extended range telemetry link to maintain the link between the aircraft autopilot and the Ground Control Station (GCS) throughout the mission.

Figure 2(a) shows the flight plan for the BLOS mission to Fox Island. The UAV launched from the north-end (NE) end of the main runway, flew 4 km to the island, circumnavigated it, and then flew back. The plan was to repeat this flight plan for as long as the aircraft endurance would allow. For this mission one of our gasoline-powered GiantStik aircraft was used, equipped with an ArduPilot autopilot system [8]. The GiantStik featured an enlarged fuel tank which allowed approximately 40-45 minutes of useful flight time. Following successful range tests of the FPV and telemetry links, and drilling of emergency procedures, the BLOS mission was conducted on October 30, 2013. A sample image from the FPV camera during this mission may be seen in Figure 2(b). The diagonal bands are caused by digital image processing of the propeller spinning at high rates directly in front of the FPV camera.
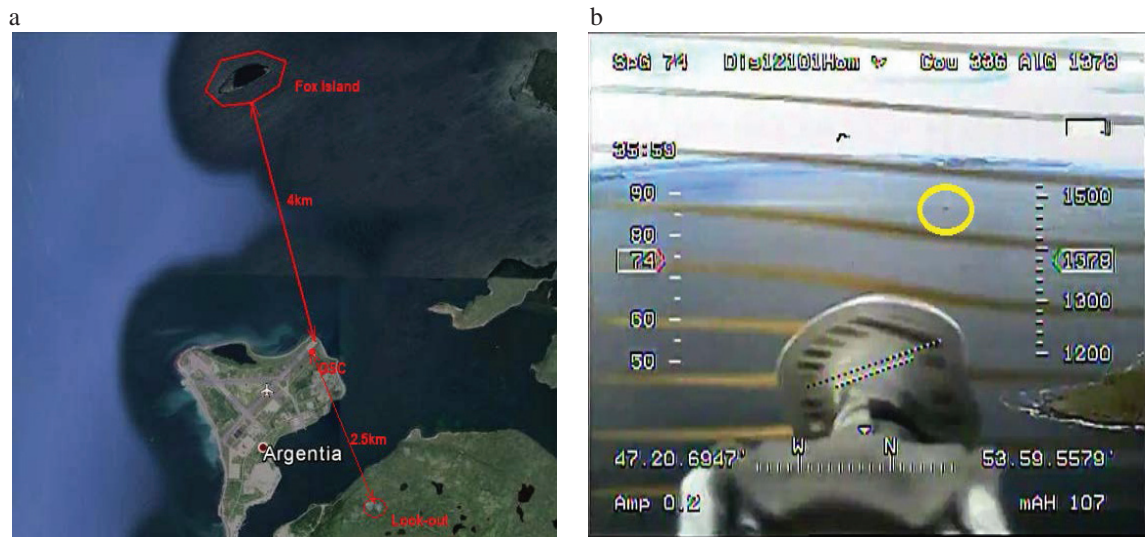
Fig. 2. (a) Beyond Line of Sight Mission to Fox Island; (b) Sample FPV.

The UAV was able to travel back and forth and circumnavigated Fox Island many times during the 45 minutes duration of the mission. The telemetry link between the autopilot and GCS worked flawlessly. We calculated that the maximum range was approximately 5.0 km, when the UAV was north of Fox Island. The FPV system maintained good video quality for most of the mission. The only times of degraded quality appeared to be brief moments when the aircraft turned its FPV video antenna away from the GCS location, usually during the return track and off to the right of Argentia (as seen from the aircraft). The video footage over Fox Island was good enough for us to notice a small fishing vessel north of the island (i.e. the circled black dot in Figure 2(b)). This was well beyond the line of sight of everyone at the GCS, and confirms the basic utility of FPV to enhance situational awareness at BLOS range.

3. Synthetic environment for BLOS control

A synthetic environment similar to a flight simulation may be one way that a virtual display could be provided to a manual pilot either to augment or replace FPV video when it is unavailable or of degraded quality. Note that the intent is to use this for emergency manual control only, and not as the means to fulfill the detect sense and avoid function at BLOS. Initial attempts to create such a virtual display are described in this section.

3.1. Flight-simulator based synthetic environment

A flight-simulator based synthetic environment was developed that permitted small UAVs to be simulated and observed in a variety of views, including FPV and external views. The basis of this simulation was an aerodynamic simulation of the Aerosonde UAV, developed in MATLAB with the assistance of a third party aerodynamic library called AeroSIM [9]. This library was developed specifically for simulating small airframes such as the Aerosonde UAV. This block set included an interface that could be used to send Flight Dynamic Model (FDM) state information (i.e. aircraft position, angles and velocities) to FlightGear (FG), an open-source Flight Simulator, for use as a visualization tool. This simulation environment is shown schematically in Figure 3(a).
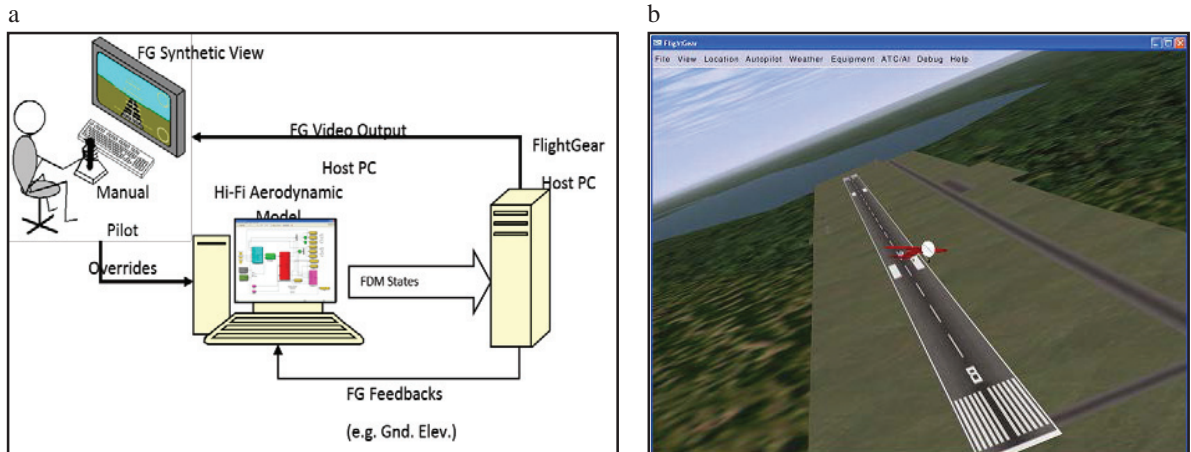
Fig. 3. (a) Small UAV Synthetic Environment; (b) FlightGear Visualization of GiantStik.

An example of the synthetic view provided is shown in Figure 3(b), which shows an external view of a GiantStik flying over the Clarenville Airfield. Note that the earth model used by the AeroSIM library and the FG graphics (i.e. the World Geodetic System 1984 Earth Ellipsoid datum [10]) is the standard datum used by most low-cost GPS receivers. Hence the simulated environment is also using the same geodetic information used by most small UAV autopilots. Therefore, even though the simulated terrain mesh is of low (30m) resolution, the position and terrain accuracy is adequate for visualizing typical small UAV operations.

3.2. Tests of synthetic environment during live UAV flight

During an Aerosonde mission, the autopilot telemetry received at the GCS is recorded to a telemetry file. These telemetry files contain a recording of the UAV position information and the autopilot control outputs during a mission. These are normally used to allow playback of a mission using a flight simulator (e.g. FlightGear) as a visualization tool. We discovered that it was possible to intercept this telemetry during flight, and once packaged into the correct FDM data structure, this could be sent to FG in real-time at the same time as the telemetry file recording. In this case the synthetic view is no longer a simulation or mission playback, but rather a representation of what is actually happening during the mission in real-time. This extended use of the FG visualization tool was demonstrated during Aerosonde flights at Clarenville airfield in October 2007. Figure 4(a) shows the computer setup used during this demonstration. The left computer hosted the FG visual display, which was driven by autopilot telemetry, intercepted from the GCS workstation (just visible to the far left) over a serial port normally used for hardware-in-the-loop testing. The computer on the right hosted the "bridge" code that accomplished this telemetry interception, and transmitted it to left computer.

The accuracy of the FG visualization tool was good enough to determine the UAV position and attitude in real time, and to show other environmental conditions during flight. During one mission it was noticed that the sun disk displayed in the FG simulation was touching the western horizon, the legal definition of the onset of sunset [11]. This information was passed along to the UAV crew, and a prompt recovery of the Aerosonde was accomplished just as a full moon, also visible in the FG visualization, was rising. This is shown in one of the post-landing pictures as shown in Figure 4(b).
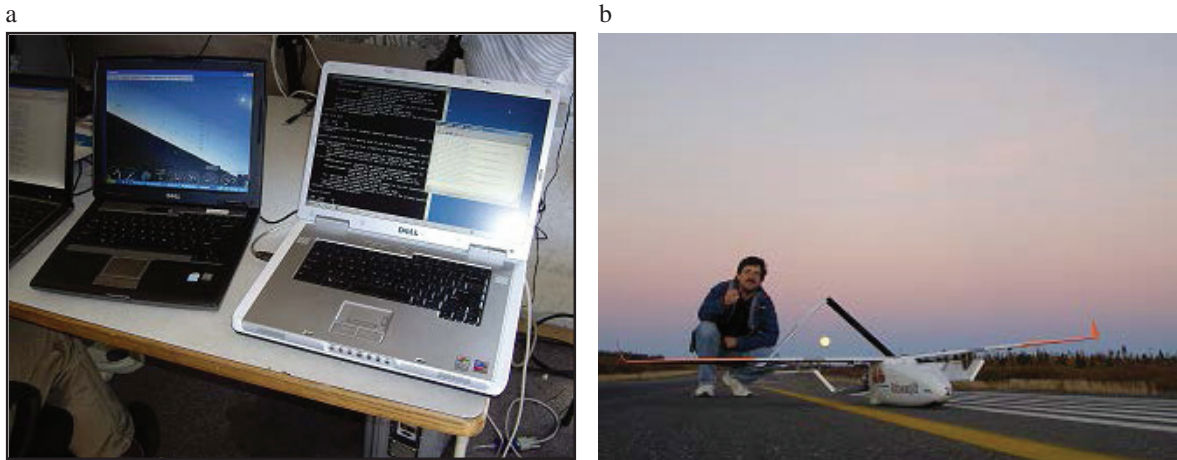
a   b

Fig. 4. (a) Synthetic Environment during UAV Flight; (b) Post-landing Picture of Aerosonde Framing a Full Moon.

3.3. Combined display for BLOS control

An extension of the synthetic environment could allow the creation of a simple yet powerful enhancement to the Aerosonde GCS. The forward (cockpit) view could be used to drive a virtual piloting display at the GCS. Assuming extended range FPV video is used, this could provide manual pilot control out to a range of at least 5 km. The synthetic view could be used to enhance this video such as in situations of poor visibility due to weather or time of day, or when video quality degrades or drops out entirely at BLOS ranges. The telemetry needed to drive the synthetic display is much smaller than the equivalent video feed, and may even be possible over very low bandwidth satellite phone links.

It would be most effective if the synthetic and real video views could be combined into a single virtual piloting display, as shown schematically in Figure 5. While the live video feed is of good quality, this would form the primary background image provided to the EP. As video imagery degrades with increased range, synthetic FG-generated elements would replace the real imagery. Even when video is good, the EP might also select some synthetic elements to be over-laid on top of the real imagery to enhance the display. The HUD is an obvious example, as would artificial enhancement of the runway location, through use of a simulator-generated outline. This would be very effective when landing in poor visibility conditions (i.e. equivalent to IFR with manned aircraft) or when at long range. The synthetic display could also display any detected entities, either targets on the ground, or other airborne targets nearby, assuming these are detected via other sensors (e.g. AIS for ships, ADS-B, TCAS for cooperative aircraft, etc.). This could happen even when these targets are well beyond normal visual range.
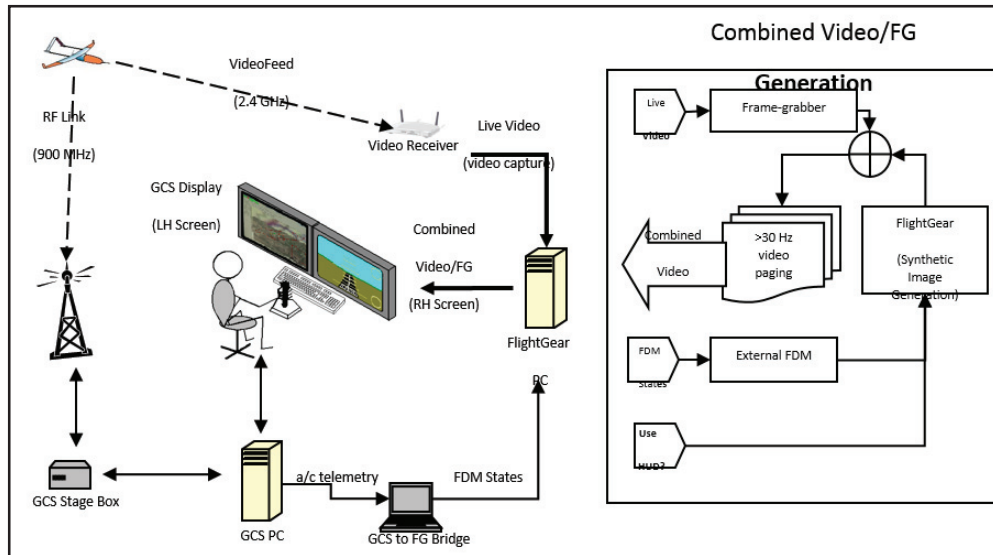
Fig. 5. Proposed Combined Video and Synthetic Display for BLOS Control.

4. Conclusion

Several different technologies have been demonstrated that may be used to enhance the manual control of a small UAV. When available, high-resolution FPV video may be one way to enhance the controllability of the small UAV, providing the link is fast and reliable. Research continues in this area, and is the subject of another paper by the authors being presented at this conference.

We have demonstrated that an extended range video link is possible to at least 5 km, assuming the use of existing high-end FPV equipment based on 5.8 GHz, the use of at least 600 mW of transmitted power and a high-gain receive antenna. Based on our own range tests, we should be able to extend this range through the use of a tracking antenna, provided we fly the small UAV at a reasonable altitude to avoid low-altitude multi-path effects especially over water.

At BLOS ranges, some form of augmented display must be used, especially as the video feed degrades. This is also true at if small UAV operations are contemplated in non-visual weather conditions including night operations. As well as extending the operational capabilities of the small UAV, there is also a safety consideration. The sole reliance on a video feed to manually control the UAV would be unwise, especially at ranges over 1 km where third person R/C control techniques are fundamentally impossible.

A synthetic environment similar to a flight simulator is one way where the position and poise of the small UAV might be represented at the GCS, at sufficient fidelity to allow a manual pilot to fly the UAV. We have already demonstrated the re-use of the Aerosonde mission playback visualization environment to display the UAV situation in real-time, through use of intercepted autopilot telemetry. The transmission range of such telemetry is possible out to the range of the autopilot data link used. During our Aerosonde flights in 2006-2008 we demonstrated a range of at least 15km using the 900 MHz piccolo II autopilot link. The Aerosonde manual suggested a maximum UHF range of 200 km depending on terrain [12]. The very low telemetry bandwidth needed to drive a synthetic display may be possible over a satellite telephone data link.

A combined BLOS display system has been proposed which uses a combination of high-resolution FPV video (when it is available) and a synthetic flight simulator display, especially when quality degrades or when non-visual flight conditions occur. Even when video is available, a manual pilot might wish to super-impose synthetic enhancements on top of the video, for example to highlight runway position, approach vectors, or any other detected entities (especially aircraft) in the area. Such an augmented display could greatly extend the range when manual control of a small UAV is feasible, and allow such control in otherwise non-visual flight conditions.

Acknowledgements

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References

[1] Transport Canada, Knowledge Requirements for Pilots of Unmanned Air Vehicle Systems (UAV) 25 kg or Less Operating within Visual Line of Sight, Document TP15263, 2014.
[2] Transport Canada, Unmanned Air Vehicle (UAV), Canadian Aviation Regulations, May 3, 2010.
[3] Federal Aviation Administration, Interim Operational Approval Guidance 08-01: Unmanned Aircraft Systems Operations in the U.S. National Airspace System, U.S. Department of Transportation, March 13, 2008.
[4] European Commission, Hearing on Light Unmanned Aircraft Systems (UAS), European Commission, Directorate F - Air Transport, October 8, 2009.
[5] Williams, K., A Summary of Unmanned Aircraft Accident/Incident Data: Human Factors Implications, Federal Aviation Administration, Oklahoma City, 2004.
[6] Transport Canada, Review and processing of an Application for a Special Flight Operations Certificate for the Operation of an Unmanned Air Vehicle (UAV) System, Staff Instruction SI-623-001, November 19, 2014, Section 6.2 (9).
[7] Eagle Tree Systems, Guardian and On-screen Display FPV, Eagle Tree Systems LLC, Bellevue, WA, 2013.
[8] 3DRobotics, ArduPilot Autopilot APM, 2013.
[9] Unmanned Dynamics, AeroSIM Aeronautical Simulation Blockset Version 1.2, Unmanned Dynamics Inc., Hood River, OR, 2006
[10] National Imagery and Mapping Agency, Department of Defense World Geodetic System 1984, National Geodetic-Intelligence Agency, January 3, 2000.
[11] MacDonald, A. F., Peppler, I. L., From the Ground Up Millennium Edition, Aviation Publishers Co. Limited, Ottawa, 2000, p.108.
[12] Aerosonde AAI, Aerosonde UAV System Product Description, Aerosonde Pty. Ltd., Notting Hill, Australia, 2006.