Chapter 3 – CAN-1: MULTI-CREW CONTROL OF A SINGLE UNMANNED AIRCRAFT

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3.1 DATES

29 September – 3 October 2008.

3.2 LOCATIONS

Faculty of Engineering, Memorial University of Newfoundland, St. John's, Newfoundland, and technical demonstration on Bell Island, Newfoundland, Canada.

3.3 SCENARIO/TASKS

The Concept Of Operation (CONOP) was to simulate a civilian Ground-Control-Station (GCS) crew as the Unmanned Aircraft System (UAS) service provider and a military crew at a Forward Control Station (FCS) as the client for the data. The civilian crew would be responsible for operation of an Unmanned Aircraft (UA) in: take-off, transition, return-to-base and landing, and hand-off the control of sensor payload and limited UA maneuver to the military crew once the UA reached the target area. The sensor data would be accessible in real time to the military FCS crew.

3.4 TECHNOLOGIES EXPLORED

In the context of multi-agent supervisory control of Unmanned Vehicle Systems (UVS), the technology matrix consists of the following cases:

1) A single crew controlling a single UVS;
2) A single crew controlling multiple UVS (force multiplication);
3) Multiple crews controlling a single UVS (this technology demonstration); and
4) Multiple crews controlling multiple UVS.

Although force multiplication (Case 2) is often cited as the ultimate goal, Case 4 is a more realistic objective because a UVS is a complex system, and often involves multiple crews in its operation. The CAN-1 technology demo focuses on Case 3 as a precursor to the implementation of Case 4. The multiple-crew CONOP in Case 3 is an example of multi-agent supervisory control: the GCS provides the high-level supervisory task of bringing the UA from the launch and recovery location while the FCS is tasked with the low-level control of the sensor

payload while the UA is on-station. This CONOP can easily be extended to Case 4 by using the GCS crew dispatching multiple UA to different FCS at different locations.

The UA often has to transit over non-segregated airspace from the launch and recovery site to the on-station sites [1],[2]. Sense And Avoid (SAA) technology [3],[4] is needed to ensure the safe integration of unmanned aircraft with other manned traffic in this transit over the non-segregated airspace. This technology demo fits within RAVEN II, a research and development program conducted by Memorial University of Newfoundland to develop SAA technology for small UA.

3.5 HUMAN FACTORS ISSUES EXPLORED

The RAVEN group is interested in the human factors issues in qualifying situation awareness, responsibilities and competence of each crew over different phases of the UA mission, in particular with respect to SAA responsibilities. The External Pilot (EP) is tasked with the see-and-avoid responsibilities at all times for visual deconfliction of traffic when the UA is within visual range of the EP. SAA duties are assigned differently over the three mission phases: launch and recovery, transit and on-station, and over two different crews: the civilian GCS crew and the military FCS crew, as shown in Table 3-1. Of particular interest is the skill competence for the external pilots at the GCS and at the FCS. It is expected that the EP at the FCS would have limited ability to tele-operate the UA, and his/her duties will mostly be the command and control of the sensor payload, and to prevent the UA from falling into the possession of hostile forces.

Table 3-1: GCS and FCS Crew Responsibilities and Competence.

Mission Phase	Crew Responsible for SAA Duties	SAA Situation Awareness	Skill Level of the EP
Launch and Recovery	GCS	Visual + Instrument	High
Transit	GCS	Instrument Only	NA
On Station	FCS	Visual	Low

3.6 UNMANNED SYSTEMS USED

The UA was an Aerosonde Mk 4.2 equipped with a Piccolo Plus autopilot from Cloudcap Technologies and an EO sensor. The UA was launched from a mobile command centre equipped with two completely redundant GCS units. The Piccolo ground control station software (version 4.0.3) and stageboxes hardware were used in the GCS and FCS units.

3.7 SUMMARY OF ANY NATO COMMUNICATIONS/COLLABORATIONS/ INTERACTIONS

The results of the study have been presented at the Task Group meeting following the demo. The following table summarizes the extent of the NATO collaboration. There have been follow up collaborations between

the Canada and the US task forces on the training requirement for the EP. There are also on-going efforts in communications, coordination and collaboration between Canada, Germany and Portugal on the planning, design, execution and analysis of multiple flights tests involving small unmanned aircraft near or over the North Atlantic Ocean, involving possibly beyond-visual-range and/or night-time operations.

	Planning/Design	***Execution***	***Analysis***
Communication	*X*	*X*	*X*
Coordination	*X*	*X*	*X*
Collaboration	*X*	*X*	*X*

3.8 SUMMARY OF TD RESULTS

3.8.1 The Planned Demo

The Canadian hosts' plan was to demonstrate the hand-off of control of the UA from the launch-and-recovery GCS crew to a FCS crew. Once the UA reached its altitude and a trimmed flight condition, the UA would be put under autopilot mode commanded by the UVS operators inside the mobile command centre. The UA would fly a fixed pattern overhead flight to simulate the transit from the launch site to the target area. After a certain time, the UA was assumed to have reached its target area. Control would then be passed off to a portable ground control station simulating a FCS crew located near the target area. The FCS crew would monitor the Electro-Optical (EO) imagery and could, optionally reprogram the flight path of the UVS for additional intelligence gathering over target area. After a certain time-on-station period, control would be passed back to the GCS to simulate the return to the launch area. The UAV would be recovered (landed) by the GCS crew.

3.8.2 The Demo Day

On the afternoon of Wednesday October 1, 2008, members of the NATO HFM-078/170 team shown in Figure 3-1 witnessed a live flight demonstration of the Aerosonde Mk 4.2 UA (named "Takunnajik" which means "Seeker" in the Innu language from the Canadian North). This required a last-minute determination to proceed based upon weather, a transit to the ferry terminal, ferry ride over to Bell Island, and transit to the remote airstrip, and all again in reverse.

Figure 3-1: NATO Team and Aerosonde UA after Landing.

3.8.3 Hand-Off Procedure

The normal procedure for a hand-off from GCS to FCS is to have the GCS operator give the FCS a signal for the hand-off while the UA is still connected to the GCS via a command and control communication Channel (A). The FCS is set up on a new communication Channel (B) on hot standby. The GCS operator commands via Channel A to the UA to switch to Channel B for communicating with the FCS. If the UA does not pick up Channel B from the FCS after a certain timeout period, e.g., 5 seconds, the UA will revert back to Channel A at the GCS. Note that the hand-off is bump-less because all the waypoints are stored in the autopilot on the UA and the UA will continue its mission until receiving further commands from the FCS after the hand-off. Also note that the UA can potentially be hijacked by a hostile FCS if the hostile FCS emits a more powerful signal on Channel A than the GCS because of the closer proximity of the FCS to the UA. This vulnerability has to be mitigated via a secure datalink.

3.8.4 Actual Events

On the day of the demo, there was only one External Pilot (EP) available on site, and it was deemed to be unsafe if control was handed off to the FCS without another EP as a safety pilot. It was decided to use the second redundant GCS as shown in Figure 3-2 to act as a FCS. The console on the right was the GCS communicating to the UA on Channel A[1] and the console on the left simulated the FCS, communicating to the UA on Channel B. Both consoles were located within the mobile command vehicle.

[1] A 900 MHz radio link was used, and channel designations A and B represents different numbered channels with the 900 MHz band.

Figure 3-2: Layout of GCS and FCS in the Mobile Command Station.

During the set-up, there was Radio Frequency Interference (RFI) between the two stageboxes providing the communication links between the two GCS's and the single UA. It was decided to put the stagebox on the left, simulating the FCS, on cold standby (turned off). After the UA was airborne and flying autonomously under autopilot on stored waypoints in the UA, a hand-off was attempted. However, a temporary link-loss from both GCS's occurred, and control was reverted back to the primary GCS automatically once the five-second timeout expired. A second hand-off was successful once more precise timing was used involving turning on the FCS stagebox during the hand-off. It should be stressed that this was not a normal or correct operating procedure for the Piccolo autopilot, but was necessary to avoid the RFI issue caused by the incorrect installation of two Piccolo GCS stageboxes in close proximity to each other. Later, a hand-off from the FCS to the GCS was accomplished successfully without needing to turn on/off any of the stageboxes. Following this demo, the UA was landed (Figure 3-1) and the mission was completed.

3.9 LESSONS LEARNED

The first lesson pertained to the skill level of the External Pilot (EP) at the launch site near the GCS and on station near the FCS. The GCS software used was not STANAG 4865 compliant, namely that both the crew at the GCS and at FCG have the full control of the autonomy of the UA, and it was unsafe to leave under full

FCS control without an experience EP acting as the safety pilot. Under STANAG 4865, the FCS might only have control of the sensors at Level 1, and the control of the air vehicle would have remained with the GCS, with an experienced external safety pilot as in the case of the visual-range mission as in the Canadian demo. From Table 3-1, the EP competency was high for the GCS crew, especially the requirement for the EP to be able to do manual landing and take-off if the UA did not have Automatic Take-Off and Landing (ATOL) capabilities. On the other hand, the EP competency for the FCS crew should be low since information gathering is the primary task and not UA flying. There is however the issue of flight termination when the UA was on station under the FCS control. The UA could be damaged or hijacked by hostile forces, and it was important the UA mission can be altered or terminated by the FCS crew to prevent the UA from falling into hostile hands.

The second lesson was spectrum management. The problem in the hand-off was peculiar to the set-up in this demo: The FCS was located next to the GCS causing RFI issues. But, the general issue of spectrum management was important. The RFI issues could have been resolved if the FCS and GCS were on different frequency bands: 900 MHz and 2.4 GHz as in the Canadian manufactured Micropilot system. Another issue was the danger of the UA being hijacked by a hostile FCS. This would be an important topic for further research.

The last lesson was on the proper use of a check list. The last-minute demo was compromised by not following the manufacturer's check list. It was known that two Piccolo stageboxes should not be located in close proximity to each other (under 2 meters). This contributed to the RFI issue. If the checklist had been followed and the mission rehearsed before the demo, the unsuccessful first hand-off could have been avoided.

3.10 STUDY CONSTRAINTS/LIMITATIONS

3.10.1 Non-Segregated Airspace

The flight was conducted in Class G non-segregated airspace in close proximity to the St. John's International airport. Due to current UVS regulatory restrictions, the entire mission was done at visual line of sight distance from the manual external pilot.

3.10.2 Limited EP Availability

The availability of a single EP was a constraint that limited the full implementation of an FCS with another EP at a different location than the GCS.

3.11 CONCLUSIONS

This demonstration marked the first live-demonstration of unmanned vehicle supervisory control within the NATO HFM-078/170 Task Group experiences. It also included hand-off demonstrations between two UA supervisory control crews, as well as between an external pilot (flying manual control) and a supervisory control station. The flight demo was well received by all and sparked many interesting crew requirement discussions, including how to improve upon the external pilot's training/tasks. Since the 2008 demo, Dr. O'Young's team has been routinely fielding multi-UA supervisory control flights for sense and avoid research.

3.12 FUTURE RESEARCH NEEDS AND PLANS IN THIS AREA

Multi-agent supervisory control of multiple UVS can be formally studied in the context of a multi-agent hybrid system. The supervisory tasks at the GCS can be modelled as discrete-event [5] tasks, such as "change of flight plans" and "return to base". The lower level task at the FCS can be considered as a continuous dynamical task, such as the manual steering of a camera pointing to a target. The interaction between the discrete tasks at the GCS level and the continuous tasks at the FCS level can be formalized as a hybrid system. Hybrid systems [6] models interactions between discrete, e.g., decision making, and continuous, e.g., UA dynamics, processes within a unified theoretical framework. The application of hybrid system theory to UA applications have been reported in [7],[8], and it is anticipated that a formal analysis of the target level of safety of an SAA system can be achievable using hybrid system as an underpinning theoretical foundation. Future collaborations between Canada, Germany and Portugal could provide valuable field data for the verification of this theoretical framework.

3.13 ACKNOWLEDGEMENTS

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3.14 REFERENCES

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