Chapter 5 – CAN-3: SUPERVISORY CONTROL: OMNISENSE

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5.1 DATES

2009 – 2012.

5.2 LOCATION

Toronto, Ontario, Canada.

5.3 SCENARIO/TASKS

Supervisory control.

5.4 TECHNOLOGIES EXPLORED

Intelligent Adaptive Agents (IAI) to manage a multi-modal display in the Ground Control Station (GCS) interface for supervisory control of an Unmanned Aerial Vehicle (UAV).

5.5 HUMAN FACTORS ISSUES EXPLORED

5.5.1 Background

Our Technology Demonstration (Tech Demo) is called OmniSense. It is currently being designed and developed to demonstrate the efficacy of a multi-modal display (i.e., the presentation of visual, auditory, and tactile information) [1] for enhancing supervisory control of an automated UAV. As a prelude to OmniSense's theoretical underpinnings, we will initially discuss our research on Intelligent Adaptive Interface (IAI) which will set the stage for our discussion of OmniSense.

Hou and his colleagues [2],[3],[4],[5] designed and developed an IAI conceptual framework. An IAI is an operator interface that dynamically changes the display and/or control characteristics of human-machine systems to adaptively react to external events in real time. A typical IAI is driven by intelligent software agents that help satisfy the decision-making and action requirements of operators under different levels of workload and task complexity by presenting the right information or action sequence proposals or by performing actions, in the right format and at the right time [2],[5],[6].

The IAI concept was investigated within a multi-UAV control context. The selected scenario involved UAV operations in support of counter-terrorist activities. The IAI was developed as part of the UAV tactical control stations for a modernized Canadian Maritime Patrol Aircraft CP-140. This work was divided into three phases.

In the first phase, the IAI concept was developed [7]. Figure 5-1 shows the IAI conceptual framework, which became the guidance for the design of the UAV GCS used for this project. A generic IAI framework has four components that are listed below:

- Situation Assessment and Support System: This component provides information about the objective state of the aircraft/vehicle/system within the context of a specific mission, and uses a knowledge-based system to evaluate the situation; this information is then provided to the Adaptation Engine component of the IAI system.
- Operator State Assessment: This component provides information about the objective and subjective state of the operator within the context of a specific mission relating to real-time analysis of his or her psychological, physiological and/or behavioural state (e.g., continuous monitoring of workload, inferences about current attentional focus, ongoing cognition, visual and verbal processing load), and intentions using extensive a priori operator knowledge (e.g., models of human cognition, control abilities, and communication).
- Adaptation Engine: This component utilizes the higher-order outputs from the Operator State Assessment and Situation Assessment systems, as well as other relevant aircraft/vehicle/system data sources, to maximize the match between aircraft/vehicle/system state, operator state, and the tactical assessments provided by the Situation Assessment system.
- Operator Machine Interface (OMI): This component provides the means by which the operator interacts with the aircraft/vehicle/system to satisfy mission tasks and goals. This is also the means by which, if applicable, the operator interacts with the intelligent adaptive system (e.g., a tasking interface manager).

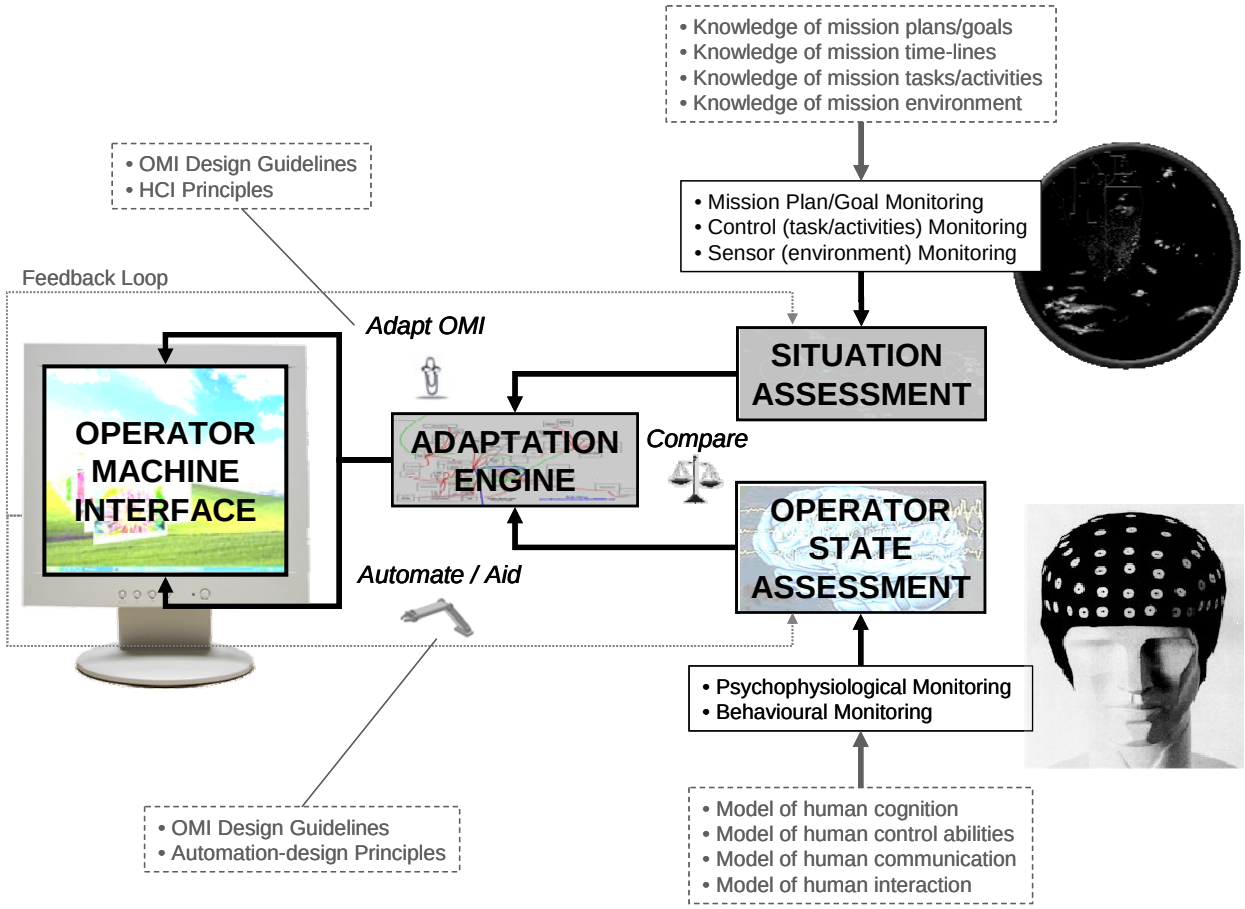

Figure 5-1: Conceptual IAI Architecture.

The IAI framework is a closed-loop system in which a feedback loop re-samples operator state and situation assessment following the adaptation of the OMI and/or automation. The goal is to adjust the level of adaptation so that optimal operator states (e.g., performance and workload) are attained and maintained. Based on this framework, a methodology was produced to analyze UAV operations in a counter-terrorist mission scenario. The scenario reflected a portion of the 2004 Canadian Forces (CF) Atlantic Littoral ISR Experiment (ALIX) that employed a Medium-Altitude, Long-Endurance (MALE) UAV and a variety of other sensors in a littoral environment using domestic security and peace support scenarios [8]. The results from the ALIX experiment were used to develop a human-machine task network model that was then implemented in an Integrated Performance Modelling Environment (IPME) [9]. The model has two modes for controlling multiple UAVs:

1) A conventional interface (i.e., without an IAI) to control multiple UAVs; and

2) An interface with IAI automation.

The difference between mission activities with and without IAI aiding was reflected in the time taken to complete critical task sequences and task conflict frequency. The simulation showed that the use of an interface with the IAI mode permitted operators to complete critical task sequences in reduced time, even under high time pressure [2],[10].

The second phase focused on the design and implementation of IAI prototype interfaces that incorporated six system function groups: inter-crew communications, route planning, route following, screen management, data-link monitoring, and UAV sensor selection. A synthetic environment was created that followed the North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 4586 interface software protocol. The experimental environment had three control stations replicating CF CP-140 tactical compartment workstations, with a set of displays and controls for each of the UAV crew members: UAV pilot, sensor operator, and tactical navigator (Figure 5-2). The experimental environment also had an integrated video and audio data collection suite to facilitate empirical assessment of IAI concepts.

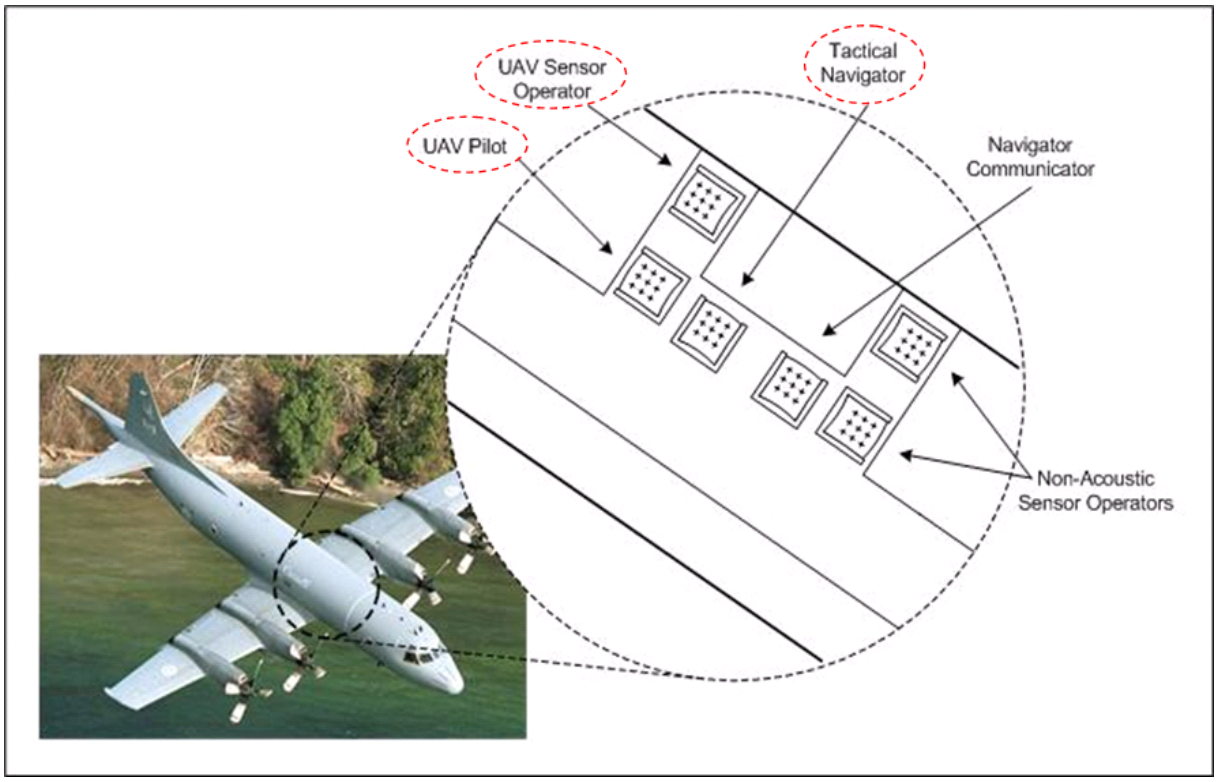

Figure 5-2: IAI Experimental Environment.

Human-in-the-loop experiments were conducted in the third phase to examine operator workload and interface adaptability with mock-up UAV control stations. Eight crews (24 operational CP-140 members) participated in the experiment. Each crew completed a two-day experiment that assessed operator interfaces with and without IAI aiding. The results showed reduced completion time for critical task sequences in the IAI mode. Also, there was a significant reduction in workload and an improvement in Situation Awareness (SA) [3],[4],[5].

The OMI component of the IAI developed by Hou and his colleagues [2],[3],[4],[5] presents information only in the visual modality. In UAV operations, an abundance of information is presented in the visual modality, resulting in cognitive overload and low situation awareness during periods of high task complexity and leading to performance degradation. Multiple-resource theory suggests that offloading information from overtaxed sensory modalities to other modalities can reduce workload [11]. The effective presentation of multi-modal information in the non-dominant modalities of hearing and touch can likely enhance the perception of

information in the dominant sensory modality of vision via redundancy and complementary information presentation [1]. For example, when the same information is mapped to multiple modalities, redundancy gains such as faster response times to an incident are observed [12]. Also, multi-modal displays can increase the bandwidth of information transfer [1]. Studies that examine methods to offload the visual modality in UAV applications have been investigated. Enhanced UAV monitoring performance was observed via a multi-modal display [13],[14],[15],[16]. For example, Calhoun et al. [15] found that a unique redundant alert for critical warnings, whether aural or tactile, helped participants differentiate warning types and improved reaction time to critical events, while participants performed multiple tasks in a simulated UAV control station.

Designers need to capitalize on the benefits of multimodal displays that would lead to effective operator decision making. This is a challenging task [17]. Unlike visual displays, the mapping of information to non-visual displays is not well understood. To date, only a few studies have explored mapping techniques for representing information in auditory displays, e.g., [18]. Tactile displays are becoming increasingly common and much has been learned regarding the use of tactile cuing in display design [19]. However, most tactile displays appear to be designed in an ad hoc fashion [20], and we are unaware of any literature that has tried to describe how to systematically map information to tactile displays. To address this problem, we are currently carrying out initial work that would lead to the development of techniques to map auditory and tactile information systematically in the OMI component of the IAI framework. This framework will be used for providing information on system faults and environmental hazards in the supervisory control of a UAV. In our present work, system faults can include a low or high engine Revolutions Per Minute (RPM) warning. Environmental hazards can include wind shear or turbulence. System faults and environmental hazards will be collectively referred to as critical events. The IAI framework is first presented before describing the tech demo, OmniSense, which is a simulated UAV GCS multi-modal display.

5.5.2 OmniSense

OmniSense focuses on the OMI component of the IAI framework and introduces the concept of a multi-modal display to the OMI. In the multi-modal interface of OmniSense, an auditory and a tactile display will be used to present specific display variables to help the operator monitor the health of the UAV. Specifically, the auditory display will present information regarding engine RPM, and the tactile display will present information regarding attitude upset. We are currently finalizing the design of the auditory and tactile display. The use of a multi-modal display is expected to improve SA, resulting in increased detection and faster response times to critical events during the cruise and landing phases of a UAV operation.

The current project contrasts OmniSense with a visual-only GCS interface. The experimental task requires participants to fly the UAV as the primary task, while also performing a secondary number monitoring task adapted from Sethumadhavan [21]. The secondary task was included to be representative of a multi-task environment where the participant needs to exhibit good performance in multiple, concurrent tasks. Operator supervisory control will be assessed as a function of display type, the number of critical events, and piloting experience. The project will attempt to answer the following research questions:

a) Can a multi-modal display improve detection and response time to critical events?

b) Can a multi-modal display improve SA?

c) Can a multi-modal display improve the bandwidth of information transfer?

This project will provide guidance on how the output of multi-modal information can be integrated into the OMI in the IAI framework. The results of this work will help form the preliminary conceptual framework to design intelligent software agents that will systematically map information to auditory and tactile displays

which will serve as additional components in the OMI. Future work will investigate the input of multi-modal information and examine how this can provide additional information to the Operator State Assessment. This will improve the accuracy of the Operator State Assessment that will be reported to the Adaptation Engine in the IAI framework (see Figure 5-1), which in turn can optimize the presentation of multi-modal information in the OMI.

5.5.3 Stimuli

The UAV simulation is developed in X-Plane 9.0. The simulation begins with the UAV set to launch from Vancouver International Airport, Canada. The conditions of flight are a sunny summer day at noon in July. The city of Vancouver is developed using X-Plane's software for simulating a city. X-plane has a seven level scale to determine the number of objects in the city. In our simulation, we used the fifth highest level on the scale for the city of Vancouver. However, no roadway vehicles, or any air traffic was simulated. The simulated environment for the onboard camera images was generated using a low-fidelity model and X-plane. Although high fidelity images were not required for this experiment, they can be generated using Meta-VR (Brookline, MA). The simulator has been adapted to interface with Meta-VR if required.

The GCS simulator has two screens, one screen dedicated to a map display and the Graphical User Interface (GUI) used to monitor the UAV and a second screen dedicated to the sensor view (e.g. the onboard camera) from the aircraft. The map display is used for navigating the UAV and providing a map-based view of its location, as shown in Figure 5-3 (right screen). This consists of a map displaying the city of Vancouver. An icon representing the UAV appears on the map and moves according to the UAV's flight position. Tasking the UAV is initiated by having the operator right click the UAV icon to select commands from the drop down menu (e.g. launch and land). Waypoints are created directly on the map to navigate the UAV to fly specific patterns. To set a waypoint, the operator moves the cursor to a position on the map and right clicks the mouse. A menu allows first waypoint and task the UAV to fly to the assigned series of waypoints.

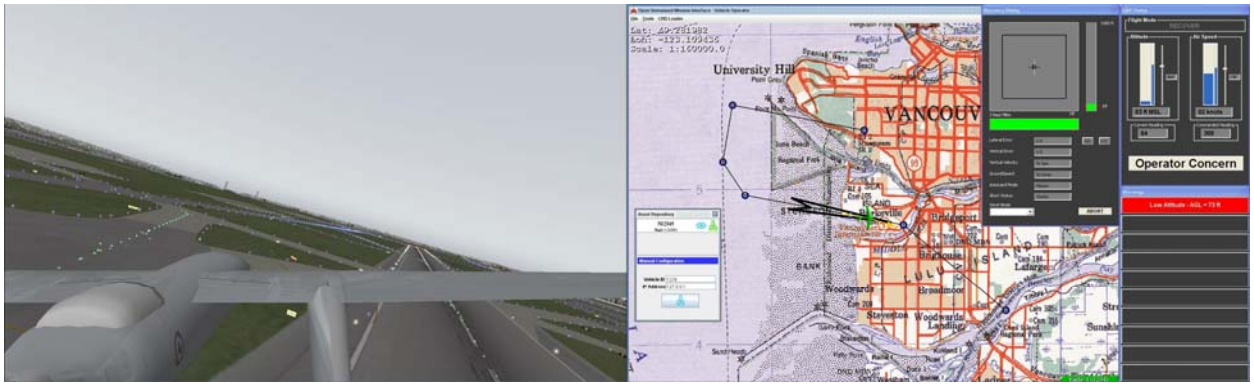

Figure 5-3: OmniSense Sensor Display and Map Display.

The GUI used to monitor the UAV is positioned to the right side of the map display screen. This GUI consists of three windows:

a) A UAV status window;

b) A warning panel; and

c) An autoland panel.

The interface is presented on the far right side of the window in Figure 5-3.

The UAV status window provides information regarding the flight status, altitude, heading, air speed, and engine RPM. The altitude and air speed are fixed such that the UAV cruises at approximately 1000 feet/mean sea level (ft/MSL) at 100 knots. This window also has the *operator concern* button that will be used to indicate that the participant has detected a critical event.

The warning panel displays warnings and messages in green, yellow or red depending on the severity of the warning or message. When multiple warnings are present, more urgent messages appear at the top of the warning panel, but otherwise, they appear in chronological order from top to bottom.

The autoland panel is visible only when the UAV switches to landing mode (i.e., autoland mode). At the top of this panel is a glideslope/localizer indicator. This indicator uses a central crosshair to specify the target glideslope and localizer point. An icon representing the UAV centres over the crosshair during a trouble-free landing, indicating that the UAV is on the glideslope and localizer path. But if upon landing, the UAV deviates from the glideslope or localizer path, the UAV icon will begin to deviate from the crosshair, providing the operator with information on the accuracy of the UAV's approach. Immediately to the right of the glideslope/localizer indicator is an altitude indicator and below it, is a lateral distance indicator. The lateral distance indicator presents the lateral distance of the UAV relative to the Touchdown Point (TDP). Both the altitude indicator and the lateral distance indicator have the *decision point* marked in red. The decision point is the point in space in which an abort landing can no longer be performed. Below these indicators are several numeric-based indicators for lateral and vertical errors, vertical descent, ground speed, the autoland mode and the abort status. The *abort* button appears at the bottom of this panel. If the *abort* button is pressed before the decision point during a landing, the autoland will be disengaged and the UAV will fly to a wave off point. If the UAV has passed the decision point, the abort command will be ignored if the *abort* button is pressed.

A second screen is dedicated to a sensor display that provides a viewpoint from the rear right stabilizer from the CF CU-170 Heron UAV. With the sensor in this position, the vantage point contains a view of the front portion of the air vehicle (Figure 5-3, left screen).

The screens in Figure 5-3 will be divided into 5 main Areas Of Interest (AOIs) for the purpose of collecting eye movement data from the participant:

a) The sensor display;

b) The map of Vancouver;

c) The UAV status panel;

d) The warning panel; and

e) The autoland panel.

The participant's eye gaze on each AOI will be analyzed for both the baseline condition (without multi-modal display) and experimental condition (with multi-modal display).

5.5.4 Experimental Design

The study is a 2 x 2 x 2 mixed design. The OmniSense display is a between-subject factor (visual-only GCS display vs. multi-modal GCS display). Flight experience (naïve vs. expert) is a second between-subject factor. The naïve group will have no pilot experience, whereas the expert group will have recently acquired at least

ten flying hours. The within-subject factor is the number of critical events (no critical events vs. multiple critical events).

The dependent variables for the UAV monitoring task are the number of critical events detected, response time to press the *operator concern* button, response time to press the *abort* button, the participant's confidence level in his/her monitoring performance to a critical event, perceived mental workload as measured via the NASA Task Load Index (NASA-TLX) [22], the participant's SA measured using a method derived from Burns et al. [23]. Participant eye movements will be monitored as a measure of visual attention. The accuracy and the response times for the secondary number monitoring task will also be evaluated to assess the participant's available bandwidth of information transfer when he/she is performing the UAV monitoring task.

5.5.5 Apparatus

The OmniSense GCS simulator is based on X-Plane 9.0 developed by Laminar Research (Portland, OR). X-plane is a flight simulation environment that also includes a plug-in architecture, which allows users to create and modify their own modules. We developed X-plane to include the Heron, which is a Medium-Altitude, Long-Endurance (MALE) UAV manufactured by Israel Aerospace Industries (Ben-Gurion Airport, Israel). This particular UAV was chosen because it is currently flown by the CF in theatre in Afghanistan.

The Open Unmanned Mission Interface (Open UMI v. 3.1) developed by Defense Technologies Inc. (Tampa, FL) is used to communicate between the GCS and the X-plane simulator. Open UMI is a common operator control interface for unmanned systems that uses current NATO STANAG 4586 and Joint Architecture for Unmanned System (JAUS) standards. STANAG 4586 requires a Vehicle Specific Module (VSM) to interface between the vehicle protocol and STANAG messages to support the GUI for the GCS. The VSM and the GUI for the GCS were designed by InnUVative Systems, Inc. (Ottawa, ON). The OmniSense GUI resembles the GUI used for the United States (US) Army Shadow UAV [24]. The participant's eye movements on the GCS display (Figure 5-3) will be monitored using two Design Interactive flexiGaze eye trackers (Orlando, FL).

Customized software was developed to run on a separate computer for the experimenter to introduce system faults (e.g., low engine RPM warning, and high engine RPM warning) and environmental hazards (e.g., turbulence, and wind shear) into the UAV flight. This software allows the experimenter to pre-program a series of faults and hazards or to introduce them in real time while the participant is controlling the UAV. The experimenter display is presented in Figure 5-4.

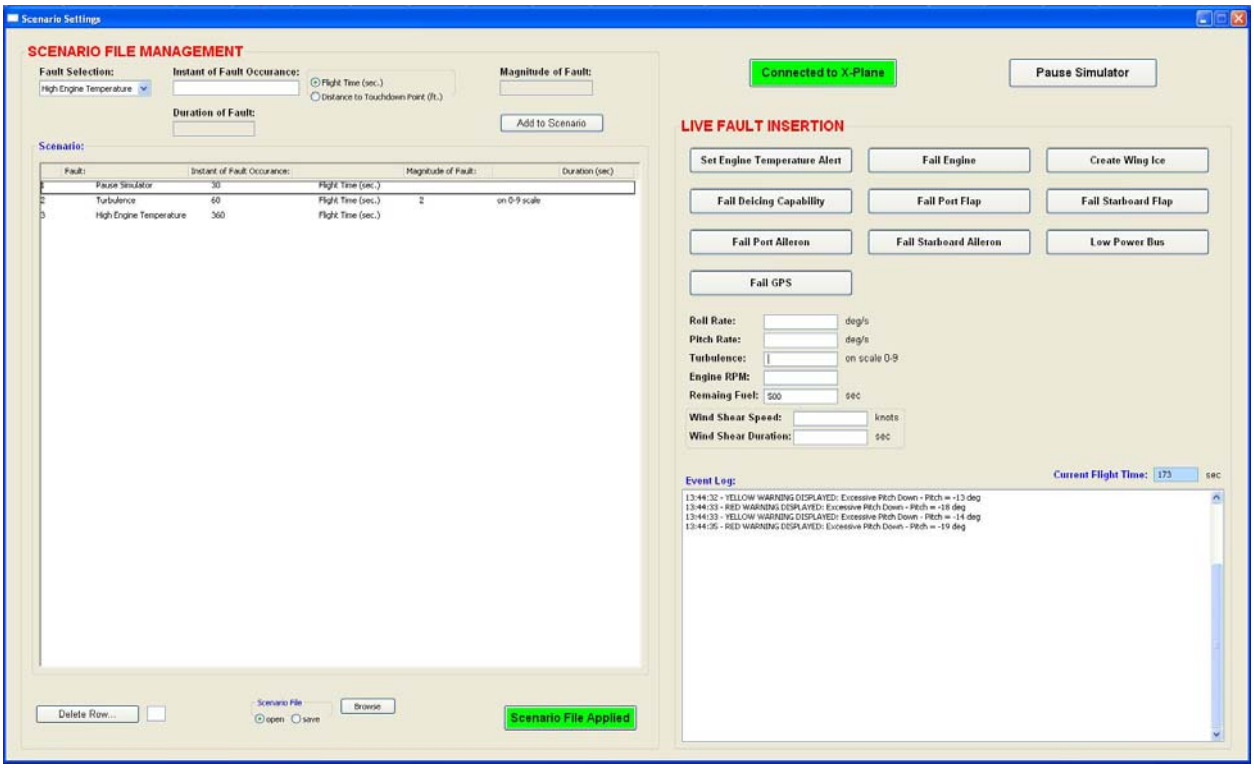

Figure 5-4: OmniSense Experimenter Display.

5.5.6 UAV Monitoring Task

The UAV monitoring task is the primary task in the current study. The participant will launch the UAV, command the UAV to predetermined waypoints, and land the UAV. The participant will also monitor for potential critical events. If a critical event occurs, the participant is instructed to respond by pressing the appropriate buttons (*Operator Concern* and/or *Abort*) depending on the phase of flight.

Each flight scenario is divided into 3 phases:

a) Take-off;

b) Cruise; and

c) Landing.

Figure 5-5 shows each phase and the key points during each section of the flight. Table 5-1 describes the events during the flight and the possible critical events that may occur.

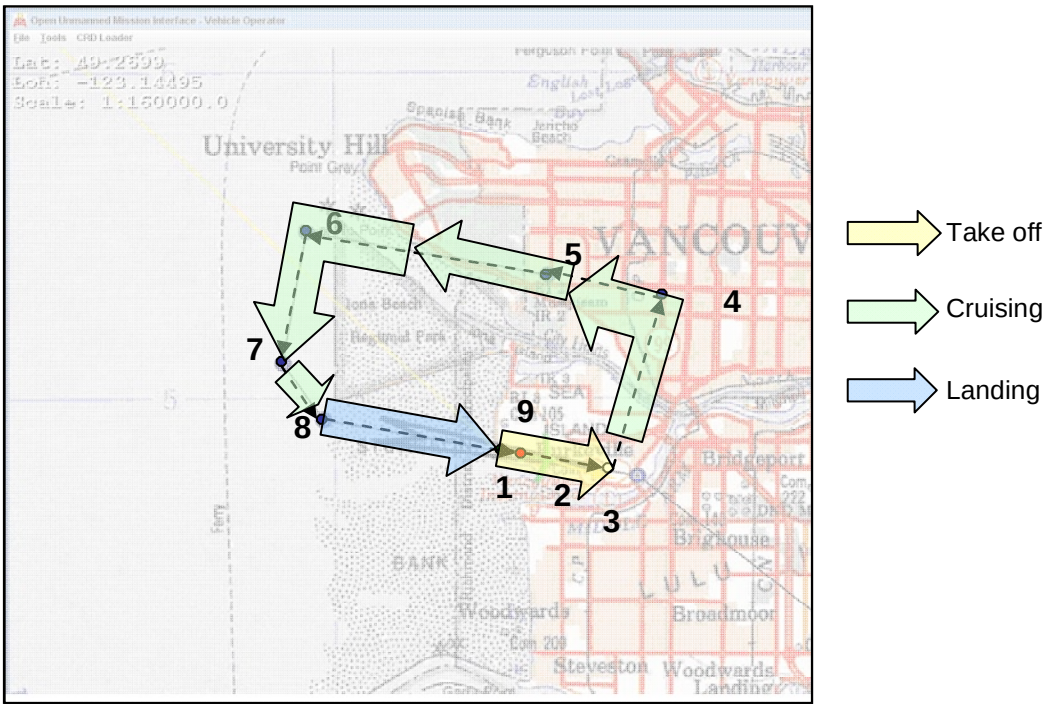

Figure 5-5: Events Associated with Each Phase of Flight (see Table 5-1 for event description).

Table 5-1: Description of Each Event Associated with Each Phase of Flight.

Phase of Flight		Flight Position	Event
Take-Off	1	Launch	Participant launches UAV
	2	400 ft	Secondary task begins
	3	700 ft	Participant tasks UAV to waypoints
Cruise	4	1st waypoint	Possible critical event (e.g., high engine RPM or wind shear)
			Possible simulation pause (initiate SA queries)
			Participant tasks UAV to recover
	5	2nd waypoint	Possible critical event (e.g., high engine RPM or wind shear)
			Possible simulation pause (initiate SA queries)
	6	3rd waypoint	Possible critical event (e.g., high engine RPM or wind shear)
			Possible simulation pause (initiate SA queries)
	7	4th waypoint	Possible critical event (e.g., high engine RPM or wind shear)
			Possible simulation pause (initiate SA queries)
Landing Approach	8	5th waypoint	Possible critical event (e.g., wind shear)
			Possible simulation pause (initiate SA queries)
Landing Touch Down / Landing Abort	9	Touch Down / Abort	UAV lands on runway (secondary task ends) or landing is aborted

In the take-off phase, the participant launches the UAV from the runway. The participant accomplishes this task by right clicking on the UAV icon and selecting the launch command from a drop-down menu. This will launch the UAV and the participant will be able to monitor its take-off from the displays. When the UAV reaches 400 ft, the number monitoring task (described below) adapted from Sethumadhavan [21] begins. When the UAV reaches 700 ft., the participant will task the UAV to the 1st waypoint. Once this command is selected, the UAV will alter its course and fly to the 1st waypoint, entering the cruise portion of the flight.

While cruising, the UAV holds at approximately 1000 ft and flies through 4 waypoints. After crossing the 1st waypoint, the participant will be tasked to land the UAV. Once the land command has been selected, the autoland interface will appear on the GCS interface and the UAV will lower its landing gear in preparation to land.

When the UAV reaches the 5th waypoint, it begins the landing portion of the flight. The UAV will engage its flaps and begin to descend. At this point, the participant must watch the autoland panel and monitor the landing of the UAV. When the UAV lands, it will touch down at the final point, which is a runway at the same airport where the UAV took off. Once the UAV descends below 100 ft / MSL, the secondary task ends.

Critical events may occur during the cruise and/or the landing phase. During the cruise phase, the participant may encounter either system faults or environmental hazards. During the landing phase, the participant may encounter an environmental hazard. The critical events will be evenly distributed across all sessions according to Table 5-2 such that each participant will experience all combinations of system faults and environmental hazards. The time of occurrence of each critical event will be randomly determined.

Table 5-2: Combinations of System Faults and Environmental Hazards That Can Occur in a Scenario.

Phase of Flight	
Cruise	**Landing**
No System Faults / No Environmental Hazards	No Environmental Hazards
System Fault or Environmental Hazard	No Environmental Hazards
No System Faults / No Environmental Hazards	Environmental Hazard
System Fault or Environmental Hazard	Environmental Hazard

The participant will be told that the primary task is to monitor and react to critical events, while carrying out the secondary task. If the UAV experiences a critical event during the cruise phase, the participant will press the *operator concern* button immediately after detecting the critical event. If the UAV experiences a critical event during the landing phase, the participant will press the *operator concern* button immediately after detecting the critical event, and will press the *abort* button if the participant believes that he/she cannot land the UAV safely. If the *abort* button is pressed during a landing, the UAV will abort the landing and fly to the wave-off point that is located at the end of the runway.

5.5.7 Number Monitoring Task

The participant will perform a secondary task in addition to monitoring the UAV for critical events. The secondary task consists of monitoring numbers adapted from Sethumadhavan [21]. A series of numbers between 100 and 199 will appear on the computer monitor at 2-second intervals. The participant will be told that a number that is less than 130 or greater than 170 represents a warning. The participant is to press the space bar on the computer keyboard immediately after detecting a warning.

5.5.8 Procedure

Participants will be tested individually. The study will be conducted over the course of three days that will not span more than a week. The participant will first receive training prior to the experimental sessions. The training includes a 20 minute multi-media tutorial on some basic principles of flight and procedures for operating a UAV. Following the video, the participant will summarize the flight procedures to demonstrate that he/she understood the concepts in the video. Subsequently, the participant will be seated in front of the three computer monitors for the duration of the study. The experimenter will then calibrate the two eye trackers. The participant will be familiarized with the UAV monitoring task and the number monitoring task. Subsequently, the participant will fly a practice scenario on the GCS simulator.

Following familiarization, the participant will proceed to the experiment. The experiment contains 12 scenarios distributed across three sessions. Session 1 contains the previously mentioned training procedure and two scenarios; Sessions 2 and Session 3 each contain five scenarios. The order of scenarios will be randomized for each participant to control for order effects. The duration of each session is two hours; sessions will be held on separate days.

Each scenario will have 3 phases: take-off, cruise, and landing. During each scenario, two SA queries will be triggered at randomly predetermined times, one during the cruise phase and one during the landing phase. When triggered, the simulation will pause and the participant will answer three questions chosen from the set of SA queries. The participant will also rate the confidence of his/her current monitoring performance on a full range confidence scale. The scale ranges from 0 – 100%, where 0% indicates that the participant undoubtedly has no confidence in his/her monitoring performance to a critical event and 100% indicates that the participant is absolutely confident in his/her monitoring performance to a critical event [25]. Once the participant has answered these questions, he/she will click on the *resume* button on the screen and the simulation will continue from the point where it paused. At the completion of the scenario, the participant will again rate the confidence of his/her monitoring performance relative to the entire scenario on a full range confidence scale. The duration of each scenario is approximately 13 minutes, which includes time for answering the SA queries, and the participant rating his/her confidence in monitoring performance to a critical event. Subsequently, the participant will be provided with a short rest break. At the completion of the last scenario in the session, the participants' perceived mental workload will be assessed using a computerized version of the NASA-TLX [22].

5.5.9 Summary

In this Tech Demo we explore effects of multi-modal display on supervisory control, SA of the mission environment, and perceived mental workload. The effects of a visual secondary task on operator performance will also be evaluated.

5.6 UNMANNED SYSTEMS USED

Multi-modal display for simulated UAV GCS.

5.7 SUMMARY OF ANY NATO COMMUNICATIONS/COLLABORATIONS/ INTERACTIONS

As indicated in Table 5-3 the OmniSense tech demo provides information pertaining to the supervisory control technology design, and development. The information was conveyed primarily at NATO HFM-170 meetings. The meetings provided an opportunity to share information on the nature of supervisory control tasks, operator interface technologies, and integration concepts that could help enhance supervisory control performance.

Table 5-3: OmniSense Technology Demonstration – Level of Interaction with NATO HFM-170.

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

5.8 SUMMARY OF TD RESULTS

Empirical data collection has not commenced. The following are preliminary potential dependent variables and associated hypotheses:

1) Critical event detection: participants will detect more critical events and detect those critical events more quickly in the multi-modal condition;
2) Response time to abort: the response time to press the abort button will significantly decrease in the multi-modal display condition;
3) Confidence in monitoring performance: the confidence in monitoring performance to a critical event will significantly increase in the multi-modal display condition;
4) Dwell times on UAV monitoring task: the dwell times (i.e., the sum of consecutive eye fixation durations in a particular AOI) on the UAV monitoring task will significantly decrease in the multi-modal display condition;
5) Secondary task accuracy: accuracy in the secondary task will significantly improve in the multi-modal display condition;
6) Situation awareness: the participant's SA will significantly improve in the multi-modal display condition;
7) Perceived mental workload: the participant's perceived mental workload, as measured by the NASA-TLX [22], will significantly decrease in the multi-modal display condition; and

8) Flight experience: the naïve participants will show poorer performance than the expert participants in the baseline condition, but will not significantly differ in performance from the expert group in the multi-modal condition. The multi-modal information is hypothesized to improve naïve performance to a greater extent than expert performance.

5.9 LESSONS LEARNED

The current study is in progress. The design and development of the OMI component of the IAI framework for OmniSense is nearly complete. The empirical data collection for the visual-only GCS interface will begin in November 2011.

5.10 STUDY CONSTRAINTS/LIMITATIONS

The experiments will be conducted in a virtual environment, not with an actual UAV.

5.11 CONCLUSIONS

The design and development of the OMI component of the IAI framework for OmniSense is nearly complete. The empirical data collection for the visual-only GCS interface will begin in November 2011. Based on earlier work showing that multi-modal displays enhanced UAV monitoring performance [13],[14],[15],[16], we anticipate that OmniSense will enhance supervisory control by providing the human operators with the ability to perform real-time monitoring of critical variables that would otherwise be undetected if eye gaze was directed elsewhere. The benefit of OmniSense is anticipated to be particularly evident in an increase in the detection of critical events, a reduction of response times to critical events, and increased SA. This suggests that the OmniSense solution will be more effective than a visually-only GCS interface.

5.12 FUTURE RESEARCH NEEDS AND PLANS IN THIS AREA

The incorporation of a multi-modal display like OmniSense into the OMI component of the IAI framework provides an example using the intelligent software agents to interact with multi-modal displays for optimizing operator-agent interactions. Furthermore, multi-modal inputs in the form of eye movements and speech assessment (e.g., loudness, vocal emotion) and facial expressions could further enhance Operator State Assessment. Future work would support the design and development of other software agents to manage multi-modal interactions and integrate them to other agents designed to assess other operator states (e.g., electroencephalography, and electrocardiography) and environmental states (e.g., weather, system status, and communication links) to enhance supervisory control of multiple UAVs.

The implication of this study is that multi-modal displays linked with IAIs have the potential to improve overall human-machine system performance if they are designed properly. However, if designed improperly, IAIs have the potential to degrade system performance by:

a) Reducing operator trust in the automation;

b) Presenting irrelevant information;

c) Presenting information that distracts the user; or in the worst-case scenario; and

d) Suppressing information that is currently required.

Additionally, other implications of this research raise the issue of the dilemma for automation and adaptation using IAI technologies for supervisory control of a UAV.

5.13 ACKNOWLEDGEMENTS

This study was funded by Defence Research and Development Canada Partner Group 13QH (Command).

5.14 REFERENCES

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