Baseline and Multimodal UAV GCS Interface Design

Progress Report

September, 2012 – March, 2013
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Abstract

To improve operational effectiveness for the Canadian Forces (CF), the Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System (JUSTAS) project is acquiring a medium altitude, long-endurance (MALE) uninhabited aerial vehicle (UAV). In support of the JUSTAS project, Defence Research and Development Canada (DRDC) – Toronto is investigating the human factors issues of UAV ground control stations (GCS) interfaces for UAVs and exploring possible solutions using multimodal displays. This is the final progress report summarizes the project from September of 2012 to March of 2013 of this Baseline and Multimodal UAV GCS design and participant running.

Executive summary

Baseline and Multimodal UAV GCS Interface Design: Progress Report

Background: Uninhabited aerial vehicles (UAVs) are remotely controlled aircraft used for a variety of civilian and military applications including command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR). To improve C4ISR capability, the Canadian Forces (CF) is acquiring a medium-altitude, long-endurance (MALE) UAV under the Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System (JUSTAS) project. In support of the JUSTAS project, Defence Research and Development Canada (DRDC) – Toronto is investigating the human factors issues of UAV ground control stations (GCS) interfaces for UAVs and exploring possible solutions using multimodal displays. This project, the Baseline and Multimodal UAV GCS Interface Design, comes to the end as of March of 2011.

Results: As of March of 2013, the participant running for both the baseline and multimodal condition of the study was completed. Several issues of the experimental environment were identified and resolved. After the preliminary data organization was completed, additional participants were run to achieve the designated number of participants in the design of the experiment.

The report described the finalized of the multimodal displays and their implementation into the multimodal condition of the experiment. The auditory sonification of engine RPM and auditory warnings were designed and introduced to the experiment. The tactile display to present attitude upset of the UAV was being developed. This additional experiment was completed and the promising tactile display was implemented in the experiment.

Significance: The report discusses the completion of the participant running for both the baseline and multimodal conditions of the experiment. The significance of the multimodal display design and the implementation of the multimodal display design to the experiment are also addressed.

Future plans: The project comes to the end as of March of 2013. The future plans of the project are to start data analysis for the baseline and multimodal condition for participants to explore the significance of the multimodal display in the UAV GCS scenarios.

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1 Introduction

An Uninhabited Aerial Vehicle (UAV) is an aircraft system without an onboard pilot or crew. The UAV is controlled from a Ground Control Station (GCS). Today's UAVs are highly automated and to some extent, autonomous. UAVs can be directed to follow a pre-programmed mission; they can fly to designated waypoints, fly specific patterns, correct for course deviations and hold above a particular coordinate or target. Some UAVs can perform automated take-off and landing (e.g., the CU-170 Heron used by the Canadian Forces). UAV developers argue that automation and autonomy provide several benefits: (a) increased flight safety; (b) simplified operations; (c) lower operating costs; and (d) reduced operator workload (Attar, 2005). However, these benefits are not always realized. Along with the benefits of automation, some disadvantages occur such as loss of situation awareness (Endsley and Kiris, 1995; Endsley, 1996), loss of supervisory control (Parasuraman, Molloy, Mouloua, & Hilburn, 1996; Sheridan, 1987), information deprivation that occurs from remote operations (Manning, Rash, LeDuc, Noback, & McKeon, 2004), and high workload levels for operators (Lee, 2008; Woods, 1996). These issues point to the need for improved interfaces to help these operators remain in the loop and maintain situation awareness during the remote monitoring tasks typical of UAV monitoring.

The work described in this report is in support of the Canadian Forces (CF) Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System (JUSTAS) project. The JUSTAS project entails the acquisition of a medium-altitude, long-endurance (MALE) UAV. This work is directed towards understanding the human monitoring challenges with UAVs similar to the UAVs that could be acquired through the JUSTAS project. Further, this project will explore the use of multimodal interfaces for UAV control leading to new design criteria for UAV ground control stations, or improved requirements for future acquisitions.

This work builds on the work of Giang et al., 2010 which reviewed the current research on multimodal displays and ecological displays for UAV control. This report is a late-project progress report detailing the work that has occurred in order to convey participant running of the two GCS designs. One of the GCS designs is a visual interface (called the “baseline condition”), essentially simulating as closely as possible the current interface for the Heron UAV. The other design is a multimodal interface where tactile and auditory information will be added to the interface to see if this new information can improve operator performance and situation awareness.

This is the last call-up of the project. This work occurred between September of 2012 and March of 2013 to support the design and testing of a multimodal Uninhabited Aerial Vehicle (UAV) Ground Control Station (GCS) simulator with novice and expert participants. This report will outline the progress in the three aspects above. In September of 2012, the evaluation of the GCS Multimodal Condition was started.

2 Design and Implementation of the Multimodal Displays

As of March of 2013 the evaluation of the multimodal displays for the GCS Multimodal Condition has been completed but the data has not yet been analyzed. This section will follow the discussion of the progress report Yeti et al., 2012) 8148-07 and describe the evaluation of the multimodal displays in the multimodal condition of the experiment.

2.1 Implementation of the Auditory Display

In the last contract call-up, the design of the auditory display was completed to integrate the Tucker Davis Technologies (TDT) System 3 into the experiment. An auditory circuit was built under the TDT System 3 development environment to produce the sonification of the UAV engine as well as the two overlay auditory alarms. Silent gaps have been added between two bursts of alarms to ensure that individual bursts could be distinguished. During the period of this call-up, the auditory circuit has been adjusted to present auditory sonification with an appropriate sound level to the participants over an AKG K501 headset. The signal-to-noise ratio of the auditory warnings was approximately 8 dB.

2.2 Implementation of the Tactile Display

A 3x3 grid for tactors deployment on the vest was implemented as the tactile display. Prior to September 2012, an experiment was conducted to examine four potential tactile display designs. The most promising design, based on discriminability and appropriate perceived urgency mappings was implemented as the tactile display in the multimodal condition of this experiment.

3 Participant Running in GCS Multimodal Condition

From September of 2012 to January of 2013, the multimodal interface was evaluated. Subsequently, a preliminary data cleansing was conducted in order to remove extraneous or faulty data. The results of the data cleansing showed that the data of some participants was corrupted, due to known and unknown system failures. Therefore, several additional participants were recruited and run from January of 2013 to March of 2013, to replace those participants with the corrupted data. In this section the procedures and events of the multimodal evaluation have been reported.

3.1 Experimental Protocol

Each participant was presented with an information package and was asked to sign a consent form prior to the start of the experiment. In August of 2012, the consent form and the information package were updated to have three major changes. The first change on the consent form and the information package was to add a question to acquire age of participants during the experiment. The intent of the question was to provide more precise information about the subject group for future data analysis and reporting. The question on age was added to the existing questionnaire in the training session. In the training session, participants were asked to complete the questionnaire after two practice scenarios were played. The questionnaire was used in running of the baseline condition. The second change was to include facts about overall sound level and pressure level during the experiment, because in the multimodal condition participants were tested with auditory and tactile signals. The third change was to revise the amount of remuneration. To allow for testing that the auditory and tactile equipment was operating properly, the length of the first session was increased by one hour. Table 1 shows the comparison of remuneration between the baseline condition and the multimodal condition.

Table 1. Comparison of remuneration between the baseline condition and the multimodal condition

Session	Hourly Rate	Total for 2-hour Session
Session 1	$10/hour	$20
Session 2	$20/hour	$40
Session 3	$30.60/hour	$61.20

a. Baseline condition (total amount: $121.20)

Session	Hourly Rate	Total for 2-hour Session
Session 1	$13.40/hour	$40.20
Session 2	$20/hour	$40
Session 3	$30.60/hour	$61.20

b. Multimodal condition (total amount: $141.40)

3.2 Experiment Room Setup

Due to laboratory renovations, the experimental setup was located in a different room from January 2012 until May 2012. During this time period, the baseline condition was run. In May of

2012, the original experimental room was fully renovated. In September of 2012, the participant running of the GCS Multimodal Condition was started in the original experimental room. After the completion of this running, all the additional participants were also taken in the original experimental room (Figure 1). Conditions between the two rooms were matched as closely as possible.

The original experimental room	The alternative experimental room	The original experimental room
Start of the project; all tests, pilot studies, etc.	GCS Baseline Condition	GCS Multimodal Condition; running of additional participants

Figure 1. The GCS experiment rooms

Similar to the set-up in the alternative experimental room (where we completed the participant running of the GCS Baseline Condition), a partition was set in the original experiment room to guarantee the minimal disruption of the experimenter and participant. A video camera was placed in the Participant Zone. The video camera only monitored the computer screens of the GCS system in the Participant Zone. The experimenter could access the video camera in the Experimenter Zone.

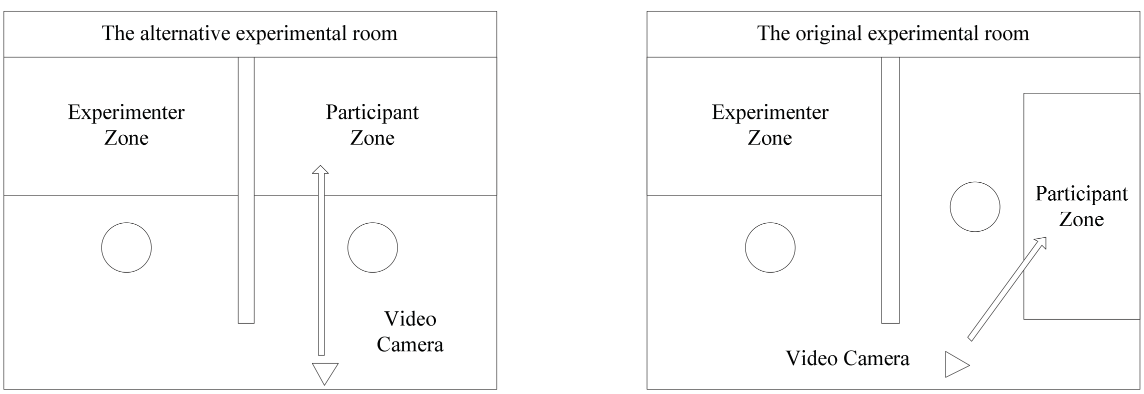

Figure 2. The partition in the GCS experiment room

3.3 Modified Participant Recruitment Process

The recruitment of participants for the GCS Multimodal Condition was started in August of 2012, prior to the experiment. The experiment was conducted in two participant groups. The naive subject group consisted of participants with no pilot experience; the expert subject group consisted of participants with at least 10 hours of pilot experience. We used the same methods in recruiting the naive participants and the expert participants. However, the participants were required to self-declare if they were naive or expert within the registration. Such recruitment methods included online registration webpages and posters on the campus of University of Waterloo and to the local flying club, Wings over Waterloo. The recruitment information received ethics clearance by Ethics Office of University of Waterloo prior to the experiment.

One challenge was to fit the participants into the experiment calendar. Similar to the GCS Baseline Condition, each participant was required to come in for three sessions. However in the GCS Multimodal Condition, the length of each session was not equal - 3 hours to complete the first session and 2 hours to complete either of the second and third session. In order to resolve this problem, an online scheduling system was set up to recruit participants.

To register for the experiment, participants were asked to visit the online scheduling system. First, participants were asked to complete a questionnaire similar to Figure 3 to ensure they were qualified to participate in the experiment. Participants should have self-reported normal hearing and have no discomfort of vibrotactile signals on the skin of their back, due to the existence of auditory and tactile interfaces in the GCS Multimodal Condition.

Annex A **Qualifications:**

1. Are you an expert participant (at least 10 hours of pilot experience) or a naive participant?
   - Expert
   - Naive

2. Normal vision is required to attend this experiment. Both naked eye normal vision and normal vision with contact lens are acceptable. Apologize but those wearing glasses need not apply. Please choose one of the following:
   - Normal vision (naked eye)
   - Normal vision (contact lens)
   - None of above

3. Do you have normal hearning ability? You will be asked to wear a headset in the experiment.
   - Yes
   - No

4. Do you have any pain or discomfort on the skin in your back? You will be asked to wear a vest with vibrotactile units.
   - Yes
   - No

Figure 3. Questionnaire for qualifications

After the qualifications were verified by the experimenter, participants were directed to a calendar view (Figure 4). The calendar was updated in real time to show the current available time slots. At the beginning of each week (Sunday), the experimenters published available time slots for the week. Initially, the duration of each available time slot was marked as 3 hours for the first session. Up to three time slots could be arranged per day, which were: 10:00am to 1:00pm, 1:30pm to 4:30pm and 5:00pm to 8:00pm. A minimum half-hour gap was set between two time slots to allow equipment preparation and data backup. The three time slots were adjustable in special situations, however participants were asked to contact the experimenters to complete such changes.

Each participant was asked to choose three empty time slots from the calendar to book his or her experiment. The first session which took 3 hours to complete was booked as-is. However, participants were informed that the second and third sessions were subject to the start time, because each of them took only 2 hours to complete. When the booking was completed, the experimenter manually modified the duration of the second and third sessions from 3 hours to 2 hours. All sessions were expected to be completed within one week, and no more than one session could be booked per day. The online booking system was programed to ensure the two requirements above.

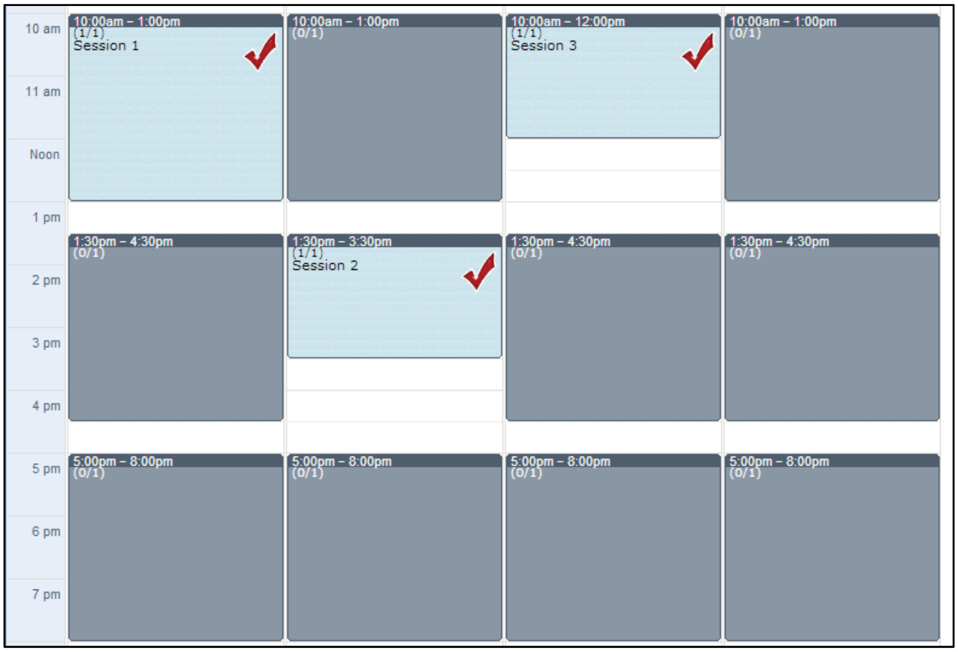

Figure 4. The participant scheduling method

Participants were asked to complete all three sessions within one week. This made scheduling difficult with three time-slots per day, and only 15 possible slots each week. The experimental procedure was changed to allow for three sessions within 7 days instead of one working week to make scheduling easier, but no-shows and cancellations late in the week still resulted in scheduling conflicts. The default time-slots on the calendar were: 10am-1pm, 1:30pm- 4:30pm, and 5pm- 8pm. The time-slots could be adjusted regarding the special need of participants, but all sessions should be arranged no earlier than 9am and no later than 9pm due to security reasons.

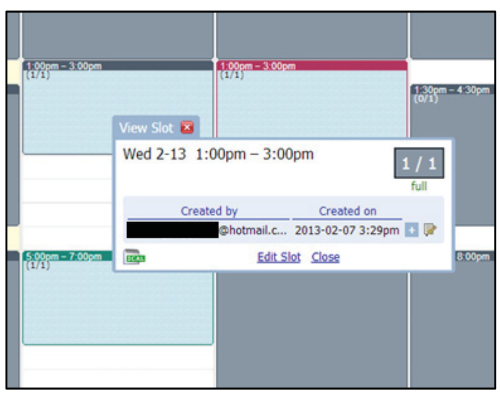

Figure 5. An example of bookings

3.4 Summary of Experiment Completion

From September of 2012 to March of 2013, 30 naive participants and 9 expert participants successfully completed the GCS Multimodal Condition experiment (Table 1).

Table 2. Participant Status of the GCS Multimodal Condition

	Number of Naive	Number of Expert

	Participants	Participants
Expected	30	10
Successfully Completed	30	9
Recruited	34	10
Failed	4	1
Failed in the first session	3	1
Failed in the second session	1	n/a
Failed in the third session	n/a	n/a
Failure Rate	12%	10%

At the beginning of each session, the participant was required to complete an eye calibration test to ensure the participant's eye movement during the simulation could be recorded by the eyetracking system. The failure of any eye calibration resulted in the participant being requested to terminate the experiment. In Table 2 above this is reflected as a "failure". The total failure rate of both naive participants and expert participants was 11%, and there was no noticeable difference of the failure rate between naive participants and expert participants.

3.5 System Failures and Defects

Overall, the GCS system was stable during the running of the multimodal condition. All the system failures that occurred during the experimental sessions in this call-up were known previously. The experimenters observed, diagnosed and handled the system failures by consulting documented procedures established when running the baseline condition. The types of failures are documented below.

3.5.1 Scenario Manager Froze on Experimenter Computer

The most frequent system failure was a crash on the experimental computer. Participants visually observed the following popup message on the monitor: "X-Plane Software has encountered a problem and needs to close". All log files up to that point were kept and there was no data loss up to this point.

Reason: Currently unknown.

Solution: Confirm data had been saved correctly. If no events occurred, the scenario could be restarted, otherwise we used only data collected up to that point.

3.5.2 Replacement of the Graphic Acceleration Card on Xplane Computer

In February of 2013, the xplane computer experienced a fatal failure while running an experiment. The xplane computer crashed a few minutes after each time it booted. The experiment has to be terminated before the problem was solved.

Reason: On further diagnosis, the problem was determined to be the failure of the cooling fan on the graphic acceleration card on the computer.

Solution: The graphic card was replaced. As the exact model of the graphic acceleration card was no longer available in the market, an equivalent model provided by the same chipset manufacturer was used. Before the experiment was resumed, an evaluation was taken to ensure the participants perceived the same interface visually throughout the simulation and time to render images was equivalent.

3.6 Preliminary Data Cleansing

The analysis of experimental data for the baseline condition and the multimodal condition of this experiment started in January of 2013. Each participant was asked to complete two practice scenarios and twelve formal scenarios. Only the twelve formal scenarios of each participant were analyzed. Prior to the analysis, the experimental data was organised. There were two major reasons to proceed with the data cleansing. First, the experimental data for each participant was recorded on various computers. Secondly, some of the experimental data was corrupted due to known system failures which have been discussed in the last contract report (call-up 8148-07). The corrupted data were replaced by data collected from running of the additional participants, which is discussed in Section 4.

At the time of writing this contract report (March of 2013), the preliminary data cleansing was ongoing. The first step in the data cleansing was to collect data from the three computers as presented in Figure 6 to one folder named by the identification of each participant.

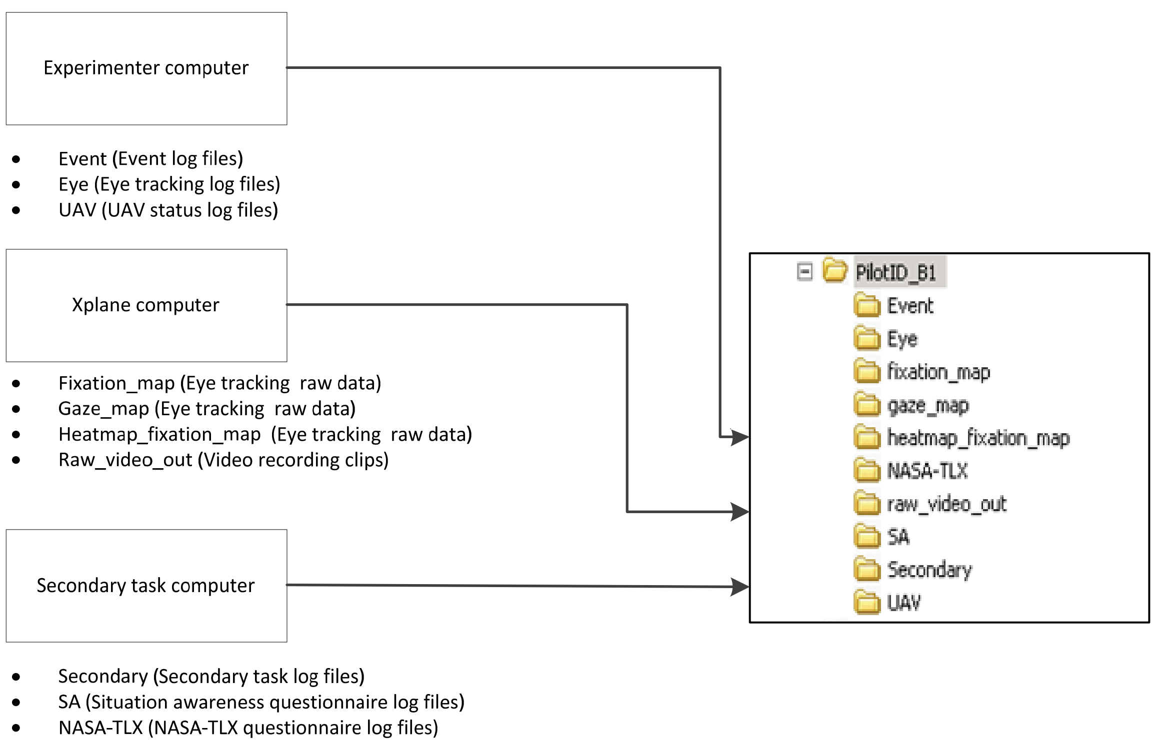

Figure 6. Data organization

There were several methods that have been used to clean the data:

1. General log files for each scenario

The general occurrences of each scenario were described by several log files which were recorded on the experimental computer. The experimental computer was controlled by the experimenter during the sessions to load, to start and stop the scenarios. The Event log file recorded all the important events occurred during the presentation of each scenario, including the occurrence of each critical event. The event log file also collected participant's response to such event, such as pressing of the "operator concern" button and the "abort" button. Another important variable coming from the event log file was the presentation of tactile stimuli. In the file, the magnitude of the vibration was recorded. By March of 2013, data cleansing for the event log file has been started, while the other two types of log files (UAV log file and eye tracking file) have not been started yet.

2. Eye tracking raw data and video clips

The eye tracking raw data was recorded and stored on the xplane computer, where the participants operated the GCS simulator. Data cleansing for such data has not been started by the time of writing this report. Video recording of the desktop of the xplane computer was also located on the xplane computer. The video recording showed exact the same display the participants were presented throughout the experiment. The cleansing of this type of data has been started on January of 2013.

3. Secondary task data and questionnaire data

The cleansing of the secondary task data has started. In each scenario, the secondary task data began shortly after the UAV was launched, and the participants were asked to response to the secondary task monitor during the scenario. However, it has been found from the video clips that during the occurrence of the "xplane encountered an error", which was a known system failure, an error dialog partially obscured the map area of the screen. This error may have disturbed participants while performing the secondary task. Thus, all the secondary data (a.k.a. responses from participants) was removed during the presentation of the error dialog.

4 Additional Participants

After the completion of the participant running of the GCS Multimodal Condition, the experimental data was cleaned and organized. More details of this process can be found in Section 3. The results of the data cleansing showed that data files of some participants were corrupted due to system failures. Several additional participants were recruited and run to replace participants whose data was seriously corrupted.

Table 3. Additional Participant Running Status

	GCS Baseline Condition		GCS Multimodal Condition	
	Nave	Expert	Naive	Expert
Expected	4	2	5	-
Successfully Completed	4	2	5	-
Recruited	5	2	6	-
Failed	1	-	1	-
- Failed in the first session	1	-	1	-
- Failed in the second session	-	-	-	-
- Failed in the third session	-	-	-	-
Failure Rate	20%	-	17%	-

Table 2 shows the summary of running additional participants for the baseline condition and the multimodal condition. No expert participants were involved in the multimodal condition, because the restriction of data cleansing progress as well as the lack of sources for recruiting expert participants.

5 Summary

In summary, considerable progress has been made between September of 2012 to March of 2013. The running of participants in the GCS multimodal condition has been completed, and the preliminary data analysis has been started. Running of the additional participants for both the baseline condition and the multimodal condition was also completed.

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List of symbols/abbreviations/acronyms/initialisms

CF	Canadian Forces
DND	Department of National Defence
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
GCS	Ground Control Station
HFES	Human Factors Ergonomics Society
HREC or DRDC HREC	Defence Research and Development Canada Human Research Ethics Committee
HUD	Heads Up Display
JUSTAS	Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System
MALE	Medium-altitude, Long-endurance
MAUVe	Multiple Autonomous Unmanned Vehicle Experimental
NASA-TLX	NASA Task Load Index
ORE or UW ORE	University of Waterloo Office of Research Ethics
RPM	Revolutions per minute
RPvdsEX	Real-Time Processor Visual Design Studio
R&D	Research & Development
SA	Situation Awareness
SOW	Statement of Work
UAV	Uninhabited Aerial Vehicle