TRAINING REMOTELY PILOTED AIRCRAFT OPERATIONS AND DATA EXPLOITATION: DEVELOPMENT OF A TESTBED FOR INTEGRATED GROUND CONTROL STATION EXPERIMENTATION AND REHEARSAL (TIGER)

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Remotely Piloted Aircraft (RPA) aircrews have dynamic, fast-paced operations and generally fly more hours than many manned platforms. The operational tempo does not allow sufficient time for training the less frequently encountered mission sets such as weapons employment or emergency operations. The United States Air Force Research Laboratory (AFRL) developed the Predator Research Integrated Networked Combat Environment (PRINCE), a medium-fidelity, non-proprietary, networkable RPA simulator, to combat this issue. The RPA pilot and sensor operator are only one component of the Planning and Direction, Collection, Processing and Exploitation, Analysis and Production, and Dissemination (PCPAD) process (i.e., the PC). The other half of the team is comprised of the intelligence analysts, who conduct the PAD portion of the process. Although RPA crews and analysts work together every day, they typically do not train together. AFRL's Warfighter Readiness Research Division and Defence Research and Development Canada (DRDC) – Toronto Research Centre have initiated a collaborative effort to take the flexible infrastructure from PRINCE and develop a system to research training for an integrated team for ISR operations. The Testbed for Integrated Ground Control Station Experimentation and Rehearsal (TIGER) was developed to assess training requirements for a pilot, sensor operator and an intelligence analysis team. TIGER supports the development of collective training and also provides DRDC with the capacity to assess new interface concepts. This paper documents the lessons learned from the development of this system and results from an initial evaluation of the system.

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INTRODUCTION

The United States Air Force has been conducting Remotely Piloted Aircraft (RPA) operations since the mid-eighties. A key use of RPAs is to provide sources of intelligence, surveillance and reconnaissance (ISR) data as well as participate in targeting missions around the world. ISR data collection and analysis has become an essential piece of both war and peacetime military operations in uncontested environments. Motion imagery collected from these platforms is screened and assessed to determine the content that is useful to process, analyze and disseminate within the Air Force Distributed Common Ground System (DCGS). Processing, exploitation and dissemination (PED) teams work to exploit the video collected by RPAs and other collection platforms. PED teams are usually comprised of multiple types of analysis specialists who generally convert collected data into intelligence that is useful to the warfighter and to leadership. Though typically operating from separate locations and under separate commands, RPA and PED teams are connected through a common thread of the data that they jointly collect, process, and disseminate.

The fast-paced operational tempo of RPAs typically limits the amount of time remaining in a typical duty day to complete training requirements. A similar challenge exists for the PED community. There is a large need for competent, expert analysts and little time and training resources to enable on the job training to maintain and improve their knowledge, skills and experiences. Thus, the team that is responsible for the collection and PED of the vast majority of the full motion video that is collected today has a requirement for robust, realistic, simulation-based individual, team, and team-of-teams training. Furthermore, RPA and PED teams do not frequently train together, so it is of interest to assess how training these two teams of operators in a joint operational environment would influence the individuals and teams within this team-of-teams.

The Warfighter Readiness Research Division of the Air Force Research Laboratory (AFRL) (711 HPW/RHA) performs human performance, training methodology development and research to increase the proficiency of the key knowledge, skills and experiences required for successful operations in complex operational environments. Recently, 711HPW/RHA has developed a training research program and technology capability to provide RPA training experiences to these critical warfighters. The development of the Predator Research Integrated Networked Combat Environment (PRINCE) enables targeted, simulation-based training research to close some of the training gaps that have been created within the RPA community by the high operational tempo of the recent and current warfighting efforts. Previous research from 711HPW/RHA details the development of this system and lessons learned to improve upon PRINCE and future RPA training[1]. This effort is ongoing and is targeted at improving the overall availability and quality of the training that is available for the RPA community.

The Royal Canadian Air Force (RCAF) shares the same interest in the effective collection and exploitation of ISR data. Defence Research Development Canada (DRDC) is investigating two key human factors aspects of integrating intelligence analysts into teams with the operators of data collection platforms. The immediate application is to a RPA crew concept that integrates intelligence analysts with pilot and sensor operator into a single crew, but the objective is to understand this more generally, where the data collection platform could be a manned aircraft, ship, ground vehicle, or other crewed system. The first aspect is the human-system interactions with a larger crew. The second aspect is training this larger crew.

Predator Research Integrated Networked Combat Environment (PRINCE) System

A challenge existed in 2011 that 711 HPW/RHA had no medium-fidelity RPA simulator that could be used for Distributed Mission Operations (DMO) training research. Commercial systems do not allow access into the source code so required elements such as performance tracking, scenario development, and system control cannot be integrated. The solution, known as PRINCE, developed by the 711 HPW/RHA engineering team was a low to medium cost system using game-based technology for scene generation (CryEngine) and the RPA aero model (X-Plane). On-hand ground control station shells were repurposed to house the system and save cost. Code was written based on the MQ-1 documentation which provides realistic user interfaces (e.g., touch screen menus). PRINCE has two crew positions, one for the pilot and one for the sensor operator (SO). Warfighters and subject matter experts (SMEs) have the ability to develop realistic aircrew training scenarios relevant to their current mission (e.g., ISR, Close Air Support, Combat Search and Rescue or CSAR) through an instructor operator station (IOS). PRINCE can be specifically configured and used to support readiness research studies. Feedback on the system has been positive[1]. Warfighters have mentioned anecdotally that PRINCE provides better tactical training than they have been receiving using actual aircraft and other available training systems.

Test-bed for Integrated Ground control station Experimentation and Rehearsal (TIGER)

Expanding upon the PRINCE concept and design, an RPA Ground Control Station (GCS) simulator is being jointly developed by the 711HPW/RHA and DRDC for use in research. The GCS simulator is known as TIGER. The versatility of TIGER will allow it to be used for a variety of learning and training studies as well as testing different GCS configurations to look at human system integration issues. Furthermore, the development of TIGER supports current efforts by DRDC to develop new RPA capability concepts.

TIGER provides six crew positions used for MALE RPA operations: air vehicle operator (AVO), payload operator (PO), image analyst (IMA-A), image reporter (IMA-R), intelligent analyst (INTA-A), and intelligence reporter (INTA-R). These six positions will be occupied by the study participants. Each workstation has a standard communications suite consisting of a voice radio, chat client, keyboard/mouse, and a chat monitor. Situation awareness (SA) displays show sensor imagery, a tactical map, and have sensor Command and Control (C2) planning software. Planning and reporting tools consist of Portable Flight Planning Software (PFPS) and Microsoft Office. Each position consists of computers, associated monitors, and the software required allowing for realistic mission emulation (e.g., flight controls, sensor controls, analyzing imagery, intelligence gathering, communications, chat, and mapping).

In addition, there are six additional computer workstations that are configured to support the trainers and researchers the instructor/simulator operator, a white force role player, computer generated forces controller, and two researchers. The instructor operator stations (IOSs) each have the standard communications suite, SA display, and planning/reporting tools. The IOS also has the TIGER simulation control software. The computer generated forces controller has control of the Modern Air Combat Environment (MACE) software (Battlespace Systems, Inc.).

Training and Human Performance Research Requirements

A key issue affecting the human-system interaction with a larger integrated crew of RPA operators and intelligence analysts is crew configuration. In present day operations, the two crews may not be in the same location. It is technically feasible for the intelligence analysts to be in a different building or even on a different continent. This crew arrangement could have benefits such as reduced need for forward deployment of crew members, keeping analysts near their technical and administrative support, and the ability for intelligence analysts to form crews with system operators located in many different locations. However, it can be more difficult for distributed teams to develop and maintain cohesion[2, 3, and 4]. Collaborative technologies address, but do not necessarily eliminate these barriers[4, 6]. It is important for both 711HPW/RHA and DRDC to understand how collaborative work tools, mission-specific tools, and the configuration of the crew interact in the context of the RPA mission.

Training at the team and collective level is the other key research issue on the proposed RPA GCS crew concept. Collective training is essential, given that the proposed system was conceived as a joint asset. Furthermore, collective training for operations with coalition partners is essential to align with policy for both US and Canada. The team performance and crew resource management have been shown to be important in the safety and effectiveness of RPA operations[7, 8]. Accordingly, team and collective training requirements for the proposed GCS crewing concept have been undertaken[9, 10, 11, 12], and will continue to be refined. Training for cockpit resource management for RPAs has been developed[13] and there is some evidence for its effectiveness[14]. Nevertheless, meeting these requirements warrants particular attention because of previously identified human factors issues.

Creating larger teams in the GCS may increase the need for coordination and make the team interactions more complicated. This includes the need to integrate intelligence analysts into the aviation environment of the GCS. The intelligence analysts are well-trained, and display a rich set of competencies, including SA and the ability to prioritize[15]. However, intelligence operators can be posted to a variety of positions, so they do not necessarily receive coordination training contextualized to the aviation environment commensurate with the crew resource management training commonly acquired by pilots and sensor operators in their aviation careers[16]. Understanding how to efficiently develop effective integrated GCS crews is therefore a key research issue.

The possible use of virtual, or distributed, teams to crew the GCS brings additional questions to team training. In reviewing research on distributed teams, previous research found the potential for reduced cohesiveness, diminished authority status, increased counter-normative, and impeded communication by the adoption of a distributed configuration[6]. Another study investigating undergraduates performing an analysis task, found that distributed teams, especially those with subgroups of different sizes, had greater difficulty with coordination and resolving conflict[3]. Furthermore, UAS crews in the past have reported being frustrated or distracted by taskings and inputs from outside their chain of command[17]. An RPA crew may be more susceptible to this when the technological mediation that binds them together provides the same immediacy to outsiders. It is this potential that makes the effect of distribution on team development a compelling research interest for this effort.

The Research Approach

Human research will be the primary method to undertake this team and collection training research. To obtain informative observations of teamwork under the proposed concept, and to create the relevant and complex learning experiences necessary for team training, an event-based approach to learning within a simulated environment was selected[18,19]. Furthermore, given that the proposed GCS concept that TIGER is designed to evaluate does not yet exist and that the processes and procedures for the proposed system are provisional, the research participants will be shaping the concept. Therefore, the simulation environment must enable a constructivist approach to the scenarios[20].That is, the simulation must enable the participants to leverage their existing expertise in RPA operations and related domains to scenarios to enable the crew in bringing forward new insights.

The Need for TIGER

It is these research requirements and constraints that drove requirements for TIGER. TIGER is needed to create highly representative RPA crew experiences in a team and coalition context that allows for flexibility in the nature of the systems, missions, and procedures proposed in a future

RPA concept. TIGER will then enable further research into a wider variety of situations where a set of intelligence analysts teams with operators of data collection systems.

Figure 1. TIGER Air Vehicle Operator and Sensor Operator workstations

Figure 2. TIGER workstations

METHODS

Participants

Ten current Canadian Armed Forces personnel participated in the initial TIGER evaluation, technical assessment and demonstration. Participants had experience with the Heron UAS, the Canadian Maritime Patrol Aircraft CP-140, and ground-based analysis. The 10 participants formed two crews comprising six operators: air vehicle operator (AVO), payload operator (PO), image analyst (IMA-A), image reporter (IMA-R), intelligent analyst (INTA-A), and intelligence reporter (INTA-R). To make two full crews (Crew A and Crew B) of six operators; one IMA and one INTA filled the same role in both crews.

Apparatus

The TIGER system, presented in Figures 1 and 2, is a game-based system comprising commercial off-the-shelf technologies to enhance simulation fidelity and backbone architecture. TIGER's gaming software is capable of rendering realistic operational environments, high fidelity entities with articulated parts, material specific infrared data, and highly detailed urban environments equivalent to commercial video games.

Procedure

Training

The UAS crew was brought to a common and sufficient level of knowledge and understanding about the system before the evaluation commenced. The training familiarized the participants with the major components of TIGER, providing them with overview information about system functionality and the Human Machine Interface (HMI). The training included brief vignettes through which participants worked together for the first time as a team. These vignettes presented a unique opportunity for the first-time team to leverage the functionality that that they had been taught in the individual training. At the end of the training session, participants were given a number of functional objectives to perform to demonstrate proficiency in the operation of the TIGER system prior to participating in the evaluation.

Scenario

A composite mission scenario was developed within the context of an intelligence, surveillance, target acquisition, and reconnaissance (ISTAR) environment whereby multiple ground contacts need to be identified, targeted, and engaged. The descriptions also include short verbal scripts for the experimenters to simulate third party communications, such as the interaction with a Joint Terminal Attack Controller (JTAC). These scripts provide the means by which the vignettes are linked together to form a coherent scenario 'narrative'. Mission scenario vignettes included a) pattern of life, b) convoy over-watch, c) call for direct fire, and d) call for indirect fire. The mission scenario comprised the critical tasks undertaken by the operator roles selected for the evaluation. As such, the vignettes covered tasks pertaining to RPA ISTAR mission system functions outlined by RCAF SMEs.

Performance Measurement

The evaluation used several measures to ascertain the HMI's impact on operator task accomplishment, workload, SA, and trust in the system. The following measures of performance were taken during the evaluation.

Operator Performance

Operator performance was assessed by a RCAF SME familiar with both RPA operations and observation-based evaluations of crew performance using a behavioral marker checklist. Behavioral markers are a quick and effective way of assessing operator competence by way of direct observations. They refer to a prescribed set of behaviors indicative of some aspect of performance or component skills. The behavioral markers used for the TIGER evaluation were designed to rate operators' behaviors in response to predetermined scenario events. A list of acceptable behavioral responses to generated events or tasks (e.g., mission analysis, adaptability–flexibility, decision making, SA, and communication) were developed and linked specifically to stimulus events in a scenario (i.e., these are predefined into a set of acceptable behaviors or task responses). An experienced RCAF training evaluator (with operational experience of UAS missions as AVO) was then asked to rate participants against a five-point scale of competence for each behavioral marker.

Situation Awareness

SA is a key determinant of task performance insofar as it provides the necessary information required to make critical decisions and determine the appropriate courses of action. SA can be conceptualized in terms of ‘product’ (i.e., an operator’s awareness of key SA elements at one moment in time) or in terms of ‘process’ (i.e. the processes involved in situation assessment which produce a representation in memory or product). The Situation Awareness Rating Technique (SART) was used in the evaluation as it provides a validated and practical subjective rating tool for the measurement of SA, based on personal construct dimensions associated with SA[21]. The structure of the construct dimensions comprises three related conceptual groups, which form the principal dimensions of SART: demand for attentional resources or D (complexity, variability, instability); supply of attentional resources or S (arousal, concentration, division of attention, spare mental capacity); and understanding of the situation or U (information quality, information quantity, familiarity). The evaluation used the most commonly-used 14-dimension version of SART.

Workload

Another key determinant of task performance is the workload experienced by the operator when engaging in tasks, and it can be conceptualized in terms of both physical and mental effort. Workload was measured using NASA Task Load Index (TLX). NASA-TLX is a subjective workload assessment tool that allows experimenters to perform retrospective subjective workload assessments on operator(s) working with various human-machine systems[22]. NASA-TLX is a multi-dimensional rating procedure that derives an overall workload score based on an average of ratings on six subscales: a) mental demand; b) physical demand; c) temporal demand; d) frustration level; e) effort; and f) own performance.

While the NASA-TLX requires a two-part process with paired comparisons, this evaluation utilized the Raw Task Load Index (RTLX) which does not require paired comparison weights[23]. The RTLX is a simple average of five TLX scales which has been found to have comparable means and standard deviations to the TLX, and to strongly correlate with ratings on the TLX[23]. As such, each questionnaire sub-scale was scored separately, and an aggregated score of overall workload was also computed.

Participant Feedback

Participant feedback was collected during each debriefing session after each training session throughout the evaluation week. Researchers collected verbal reports and reports summaries are included in the results section below.

RESULTS

Operator Performance

Both crews performed well across nearly all aspects of the mission; the areas that need the most performance improvement being the positioning of the RPA to optimize weapon performance (AVO), the use of EW tools to provide useful contextual information (INTA) and the timeliness of providing a targeting solution to the JTAC (Crew). In addition, Crew A was rated as poorly on teamwork items; which would have likely reduced the crew’s effectiveness across the mission.

Situation Awareness

SA scores suggest that the AVOs and POs were able to supply sufficient mental resources to meet the demands of the scenario and achieve relatively high levels of SA, which in turn led to ‘fair’ and ‘good’ levels of performance as rated by the SME. The main difference between the crews was the low levels of SA attained by both IMA roles (analyst and reporter) in Crew B. This can be accounted for by communication factors such as: a) a perceived lack of direction from the AVO resulting in the IMA-A only reacting to the situation and not thinking ahead; and (b) the IMA-R’s frustration with the lack of detailed map and satellite imagery to support reporting, and the need for additional training to perform the role (i.e., additional time needed for familiarization).

Workload

Workload scores suggest that both crews showed moderate levels of workload, which is ideal considering that lower workload levels could lead to attentional disengagement, and higher levels could lead to task overload. However, the AVO, INTA-R, and (to some extent) IMA-R roles did report low levels of workload overall which would suggest that the level of complexity for those aspects of the mission scenario should be increased to fully engage these roles. For example, the scenario could require more complex UAS maneuvering on the part of the AVO and more extensive reporting duties for both the IMA-R and INTA-R roles. Finally, many participants reported medium-to-high levels of frustration during the evaluation mission; a finding that can be accounted for from a combination of the new team composition, technical difficulties experienced during the trial, and perceived technical improvements needed for the IMA and INTA tools available on TIGER.

Participant Feedback and Objective Assessment

Participant comments and recommendations were collected throughout the course of evaluation. In summary, the evaluation has met the following top-level objectives:

1. Demonstrate and review TIGER capability. The pattern of results reported above shows that both crews were able to perform well during the evaluation mission. In addition, the participants reported that the level of functionality implemented within TIGER was acceptable for their requirements. Finally, the measures used by the evaluation team were shown to provide useful insights into the behavior and performance at both the individual and crew level. Indeed, these measures identified several key themes for further experimentation and refinement of TIGER.

2. Establish baseline performance in the composite mission scenario of the crew using TIGER. All results reported herein can be used in the development of a baseline level of performance for future studies.

3. Provide specific guidance for the development of a customized TIGER HMI. The results of this evaluation will be used to inform the next iteration of the GCS Graphical User Interface) workstation and workspace design concepts

DISCUSSION

The initial employment of TIGER attained several achievements. First, the TIGER system and the scenario set generated the complexity needed to study team performance. The crew was forced to coordinate, communicate, resolve conflicts, and prioritize to achieve mission objectives. TIGER was able to provide the crewmembers with actual or representative mission tools integrated into a common GCS configuration. Although the mission tools require further refinement to enhance realism of the environment, they provided the crew with the ability to collectively perform their mission tasks in a shared synthetic environment. Additionally, the system demonstrated desired flexibility by supporting unplanned missions at short notice. Overall, throughout the evaluation week, TIGER demonstrated a high level of technical stability. Specifically, the system was sufficiently stable and agile that none of the training or evaluation scenarios or data collection activities were compromised by system failures. Finally, the TIGER system was able to generate informative data regarding individual and team performance.

In the immediate future, TIGER development will continue to enhance the capabilities that were provided in this initial evaluation. Specifically, enhancements will be made to the tools used on the intelligence analyst and intelligence reporter workstations. Also, performance metrics for the mission participants will be developed and recorded in future research using the coalition version of the Performance Effectiveness Tracking System (C-PETS). C-PETS will provide quantitative data that can be used to analyze and track individual and team performance during mission execution. Another TIGER system will be built in 2015. The current system will be moved to and reside at DRDC in Toronto. The second system will remain at Wright-Patterson Air Force Base and be used by 711HPW/RHA personnel for research and engineering development. Planned and possible future research and development include HMI research, GUI development and testing, advanced scenario development, training effectiveness research, and joint and coalition training, rehearsal, and exercise research. As the research questions are answered for TIGER within the RPA context, it will be used to study, develop and evaluate team and collective training for the broader ISR community.

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APPENDIX: LIST OF ACRONYMS

711 HPW	711th Human Performance Wing
AFRL	Air Force Research Laboratory
AVO	Air Vehicle Operator
BSI	Battlespace Simulations, Inc.
C2	Command and Control
C-PETS	Coalition-Performance Effectiveness Tracking System
DCGS	Distributed Common Ground System
DMO	Distributed Mission Operations
DRDC	Defence Research and Development Canada
GCS	Ground Control Station
GUI	Graphical User Interface
HMI	Human Machine Interface
IMA-A	Image Analyst
IMA-R	Image Reporter
INTA-A	Intelligence Analyst

INTA-R	Intelligence Reporter
IOS	Instructor Operation Station
ISTAR	Intelligence, Surveillance, Target Acquisition & Reconnaissance
JTAC	Joint Terminal Attack Controller
MACE	Modern Air Combat Environment
NASA TLX	National Aeronautics and Space Administration Task Load Index
PCPAD	Planning & Direction, Collection, Processing & Exploitation, Analysis & Production & Dissemination
PED	Processing, Exploitation & Dissemination
PFPS	Portable Flight Planning Software
PO	Payload Operator
PRINCE	Predator Research Integrated Networked Combat Environment
RCAF	Royal Canadian Air Force
RHA	Warfighter Readiness Research Division
RPA	Remotely Piloted Aircraft
RTLX	Raw Task Load Index
SA	Situation Awareness
SART	Situation Awareness Rating Technique
SME	Subject Matter Expert
TIGER	Testbed for Integrated Ground Control Station Experimentation and Rehearsal
UAS	Unmanned Aircraft Systems