

**MISSION SPECIALIST HUMAN-ROBOT INTERACTION
IN MICRO UNMANNED AERIAL SYSTEMS**

A Dissertation

by

JOSHUA MICHAEL PESCHEL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2012

Major Subject: Computer Science

Mission Specialist Human-Robot Interaction in Micro Unmanned Aerial Systems

Copyright 2012 Joshua Michael Peschel

**MISSION SPECIALIST HUMAN-ROBOT INTERACTION
IN MICRO UNMANNED AERIAL SYSTEMS**

A Dissertation

by

JOSHUA MICHAEL PESCHEL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Approved by:

Chair of Committee,	Robin R. Murphy
Committee Members,	John B. Mander
	Dylan A. Shell
	Dezhen Song
Head of Department,	Duncan M. Walker

August 2012

Major Subject: Computer Science

ABSTRACT

Mission Specialist Human-Robot Interaction
in Micro Unmanned Aerial Systems. (August 2012)
Joshua Michael Peschel, B.S.; M.S., Texas A&M University
Chair of Advisory Committee: Dr. Robin R. Murphy

This research investigated the *Mission Specialist* role in micro unmanned aerial systems (mUAS) and was informed by human-robot interaction (HRI) and technology findings, resulting in the design of an interface that increased the individual performance of 26 untrained CBRN (chemical, biological, radiological, nuclear) responders during two field studies, and yielded formative observations for HRI in mUAS.

Findings from the HRI literature suggested a *Mission Specialist* requires a role-specific interface that shares visual common ground with the *Pilot* role and allows active control of the unmanned aerial vehicle (UAV) payload camera. Current interaction technology prohibits this as responders view the same interface as the *Pilot* and give verbal directions for navigation and payload control. A review of interaction principles resulted in a synthesis of five design guidelines and a system architecture that were used to implement a *Mission Specialist* interface on an Apple® iPad. The Shared Roles Model was used to model the mUAS human-robot team using three formal role descriptions synthesized from the literature (*Flight Director*, *Pilot*, and *Mission Specialist*).

The *Mission Specialist* interface was evaluated through two separate field studies involving 26 CBRN experts who did not have mUAS experience. The studies consisted of 52 mission trials to surveil, evaluate, and capture imagery of a chemical train derailment incident staged at Disaster City®. Results from the experimental study showed that when a *Mission Specialist* was able to actively control the UAV payload camera and verbally coordinate with the *Pilot*, greater role empowerment (confidence, comfort, and

perceived best individual and team performance) was reported by a majority of participants for similar tasks; thus, a role-specific interface is preferred and should be used by untrained responders instead of viewing the same interface as the *Pilot* in mUAS.

Formative observations made during this research suggested: i) establishing common ground in mUAS is both verbal and visual, ii) type of coordination (active or passive) preferred by the *Mission Specialist* is affected by command-level experience and perceived responsibility for the robot, and iii) a separate *Pilot* role is necessary regardless of preferred coordination type in mUAS. This research is of importance to HRI and CBRN researchers and practitioners, as well as those in the fields of robotics, human-computer interaction, and artificial intelligence, because it found that a human *Pilot* role is necessary for assistance and understanding, and that there are hidden dependencies in the human-robot team that affect *Mission Specialist* performance.

ACKNOWLEDGMENTS

This research work was made possible by the help and support of my colleagues, friends, and family.

Professor Robin Murphy served as my dissertation advisor. It was through her human-robot interaction class that I initially came to appreciate the importance of the field and this research topic. Professor Murphy advised me during my PhD studies with honor and integrity and I appreciated most the opportunity to learn her disciplined approach to the creative process. I thank her for all that she has taught me over the years. Professors John Mander, Dezhen Song, and Dylan Shell served as the other members of my dissertation committee. I thank each of them for their suggestions and encouragement during my work on this research topic.

The field experiments for this research would not have been possible without the Disaster City® facility supported by the Texas Engineering Extension Service (TEEX) at Texas A&M University. Chief David Martin and Mr. Clint Arnett were instrumental in the planning and arranging of the facilities and responder participants. My sincere thanks go to them and the Disaster City® staff for their unique expertise and efforts. This research was supported by National Science Foundation Grant IIS-1143713, EAGER: Shared Visual Common Ground in Human-Robot Interaction for Small Unmanned Aerial Systems, the first joint grant between TEEX and the Center for Robot-Assisted Search and Rescue (CRASAR) to study human-robot interaction for the response community.

I owe special thanks to Mr. Thomas Meyer from AirRobot US, Inc., Mr. Zenon Dragan and Mr. Mark Bateson from Draganfly Innovations, Inc., and Professor Nasir Gharaibeh from the Zachry Department of Civil Engineering, for providing unique access to the unmanned aerial vehicles used in my experiments. I would like to thank Professor Clifford Nass from Stanford University and Professor Cindy Bethel from Mississippi State University for their helpful suggestions on my survey questions and experimental designs. Thanks also go to Professors Anthony Cahill and Kelly Brumbelow from the Zachry De-

partment of Civil Engineering for providing me with assistantship funding in the early part of my graduate studies.

I was very fortunate to be a member of Team UAV, unquestionably the best team from a strong research group filled with excellent students and scholars. Ms. Brittany Duncan was my office mate and pilot-in-command of Team UAV. She also holds the rather unexpected distinction of being my very last college roommate. To say this research would not have been possible without her help is an understatement; I can offer her only my sincerest thanks. Team UAV was rounded out by Mr. Adrian Jimenez Gonzalez who I thank for spending a significant amount of time keeping copious mission notes during my experiments. I would additionally like to thank the other members of the field team, Mr. Jaewook Yoo and Dr. Xiaoming Li, for their helpful feedback during the preparation of my thesis defense. Members of the Survivor Buddy Team (Vasant Srinivasan, Zack Henkel, Jessica Gonzales, Jesus Suarez, Bethany McNabb) and the Multi-Robot Systems Group (Lantao Liu, Ben Fine, Taahir Ahmed, YoungHo Kim, Jung-Hwan Kim, Yong Song, Kate Wells, Asish Ghoshal, Plamen Ivanov, Changjoo Nam, Sasin Janpuangtong) provided insightful questions during all of my AI Robotics Lab seminar talks and I thank them as well.

Finally I would like to thank my family and friends who have supported me throughout all of my studies, the most essential and influential being my wife and best friend, Cassandra Rutherford (now Professor Cassandra Rutherford). The last twelve years simply would not have been the same without her presence in my life. This work is dedicated to her unwavering love and support.

NOMENCLATURE

<i>AM</i>	Arithmetic Mean
CBRN	Chemical, Biological, Radiological, Nuclear
<i>cv_{JB}</i>	Jarque-Bera Critical Value
<i>cv_L</i>	Lilliefors Critical Value
<i>df</i>	Degrees of Freedom
<i>df_d</i>	Denominator Degrees of Freedom
<i>df_n</i>	Numerator Degrees of Freedom
eCDF	Empirical Cumulative Distribution Function
<i>GM</i>	Geometric Mean
<i>GSD</i>	Geometric Standard Deviation
HCI	Human-Computer Interaction
HRI	Human-Robot Interaction
<i>JB</i>	Jarque-Bera Test Statistic
JCS	Joint Cognitive System
<i>k</i>	Kurtosis
<i>KS</i>	Kolmogorov-Smirnov Test Statistic
<i>M</i>	Median
mUAS	Micro Unmanned Aerial Systems
<i>n</i>	Number of Data Points
<i>p</i>	Statistical Significance
<i>r_{qp}</i>	Normal Quantile Plot Correlation Coefficient
<i>R²</i>	Coefficient of Determination
<i>s</i>	Skewness
<i>SD</i>	Standard Deviation
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle

TABLE OF CONTENTS

	Page
ABSTRACT	iii
ACKNOWLEDGMENTS	v
NOMENCLATURE	vii
TABLE OF CONTENTS	viii
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
1 INTRODUCTION	1
1.1 Research Question	3
1.2 Why Focus on the <i>Mission Specialist</i> Role	4
1.3 Understanding Unmanned Aerial Vehicles	5
1.3.1 Micro Unmanned Aerial Vehicles	5
1.3.2 Other Unmanned Aerial Vehicles	6
1.4 Importance to CBRN	7
1.5 Contributions	8
1.5.1 First Focused Study of the <i>Mission Specialist</i> Role	9
1.5.2 New Guidelines for a <i>Mission Specialist</i> Interface	9
1.5.3 Unique Empirical Evaluation of the Shared Roles Model	10
1.6 Organization of the Dissertation	10
2 RELATED WORK	12
2.1 Human-Robot Team Models Related to Micro Unmanned Aerial Systems	12
2.1.1 Joint Cognitive Systems	12
2.1.2 Shared Roles Model	13
2.2 Human-Robot Interaction Literature on Micro Unmanned Aerial Systems	15
2.2.1 The Murphy 2008 Study	15
2.2.2 The Adams 2009 Study	16
2.2.3 The Oron-Gilad 2010 Study	17
2.2.4 Other Commercial Micro Unmanned Aerial Systems	18
2.3 Interaction Principles Applicable to Micro Unmanned Aerial Systems	19
2.3.1 Human-Computer Interaction Principles	19

	Page
2.3.2 Human-Robot Interaction Principles	27
2.4 Summary	32
3 THEORY AND APPROACH	33
3.1 Shared Roles Model for a Micro Unmanned Aerial System	33
3.1.1 <i>Flight Director</i> Role Description	33
3.1.2 <i>Pilot</i> Role Description	35
3.1.3 <i>Mission Specialist</i> Role Description	35
3.2 Human-Robot Interaction Findings in Micro Unmanned Aerial Systems	35
3.2.1 Small, Mobile, and Visual Displays	35
3.2.2 Shared, Duplicate, or Passive Interaction	36
3.2.3 Lack of Software-Based Interfaces	36
3.3 Recommended Design Guidelines for a <i>Mission Specialist</i> Interface	37
3.3.1 Design for Unary Interaction	37
3.3.2 Design for Adequate Data Context	37
3.3.3 Design for Natural Human Interaction	38
3.3.4 Design for Cueing and Communication	38
3.3.5 Design for Flexibility and Expansion	38
3.4 System Architecture for a <i>Mission Specialist</i> Interface	38
3.5 Summary	40
4 IMPLEMENTATION	41
4.1 Hardware Platform Description	41
4.2 Software Platform Description	43
4.3 Summary	43
5 EXPLORATORY STUDY	44
5.1 Overview	44
5.2 Participants	47
5.3 Measurements	48
5.3.1 Task Completion	48
5.3.2 Post-Assessment Surveys	48
5.3.3 Biophysical	49
5.3.4 Audio and Video	49
5.4 Results	49
5.4.1 Number of Completed Tasks	50
5.4.2 Levels of Stress	51
5.4.3 Role Empowerment	51

	Page
5.5 Observations	52
5.5.1 More Captured Images with Passive Display	52
5.5.2 Similar Captured Images for Well-Defined Tasks	53
5.5.3 Similar Levels of Stress	53
5.5.4 Lack of Adequate Visual Feedback	54
5.5.5 Greater Role Empowerment with Passive Display	54
5.6 Recommendations	54
5.6.1 Deeper Focus on Role Empowerment	55
5.6.2 More Visual Feedback on Interface	55
5.6.3 Reduce UAV Platform Latency	56
5.7 Interface Terminology Precision	56
5.8 Summary	58
6 EXPERIMENTAL METHODS AND DESIGN	60
6.1 Study Overview	60
6.2 Research Hypotheses and Expected Findings	61
6.2.1 Same or Less Task Completion Time	62
6.2.2 Same or Less Stress	62
6.2.3 Same or Greater Role Empowerment	62
6.3 Participants	62
6.4 Facilities	63
6.5 Equipment	64
6.6 Personnel	64
6.7 Pre-Assessment Survey	65
6.8 Experimental Design	65
6.9 Measuring <i>Mission Specialist</i> Performance	65
6.10 Post-Assessment Survey	66
6.11 Study Protocol	66
6.12 Contingency Plan	67
6.13 Summary	68
7 DATA ANALYSIS AND RESULTS	69
7.1 Task Completion Time Analyses and Results	69
7.1.1 Object Identification Tasks	70
7.1.2 Evaluation Tasks	76
7.1.3 Image Capture Tasks	81
7.2 Levels of Stress Analyses and Results	87
7.2.1 Heart Rate Descriptive Statistical Analyses	87
7.2.2 Heart Rate Inferential Statistical Analyses	88

	Page
7.3 Role Empowerment Analyses and Results	88
7.3.1 Locating Objects	89
7.3.2 Capturing Images	91
7.3.3 Payload Camera Tilt	91
7.3.4 Payload Camera Zoom	92
7.3.5 Perceived Best Individual and Team Performance	92
7.4 Summary	94
8 DISCUSSION	96
8.1 Task Completion Time Discussion	96
8.1.1 Object Identification Tasks	97
8.1.2 Evaluation Tasks	97
8.1.3 Image Capture Tasks	97
8.2 Levels of Stress Discussion	98
8.3 Role Empowerment Discussion	98
8.4 Formative Observations	99
8.4.1 The Commander Effect	99
8.4.2 The Responsibility Effect	100
8.5 Dimensions of the Shared Roles Model	101
8.5.1 <i>Mission Specialist</i> Control	103
8.5.2 Focused Visual Common Ground	103
8.6 Factors that May Have Impacted the Results	104
8.6.1 Hand Physiology	104
8.6.2 Novelty of the Robot	105
8.7 Summary	105
9 CONCLUSIONS AND FUTURE WORK	107
9.1 Significant Contributions and Conclusions	107
9.1.1 Theoretical Contributions	108
9.1.2 Practical Contributions	110
9.2 Future Work	112
9.2.1 Immediate Future Research Goals	112
9.2.2 Long-Term Future Research Goals	112
REFERENCES	114
APPENDIX A VERBAL ANNOUNCEMENT SCRIPT	119
APPENDIX B EXPLORATORY STUDY INFORMATION SHEET	120

APPENDIX C	EXPLORATORY STUDY CONSENT FORM	122
APPENDIX D	EXPLORATORY STUDY PRE-ASSESSMENT	124
APPENDIX E	EXPLORATORY STUDY COMMAND PROTOCOLS	128
APPENDIX F	EXPLORATORY STUDY MISSION SCRIPT	130
APPENDIX G	EXPLORATORY STUDY SCRIPT FOR FLIGHT 1	132
APPENDIX H	EXPLORATORY STUDY SCRIPT FOR FLIGHT 2	135
APPENDIX I	EXPLORATORY STUDY POST-ASSESSMENT 1	138
APPENDIX J	EXPLORATORY STUDY POST-ASSESSMENT 2	141
APPENDIX K	EXPERIMENTAL STUDY INFORMATION SHEET	144
APPENDIX L	EXPERIMENTAL STUDY CONSENT FORM	146
APPENDIX M	EXPERIMENTAL STUDY PRE-ASSESSMENT	148
APPENDIX N	EXPERIMENTAL STUDY COMMAND PROTOCOLS	171
APPENDIX O	EXPERIMENTAL STUDY MISSION SCRIPT	173
APPENDIX P	EXPERIMENTAL STUDY SCRIPT FOR FLIGHT 1	175
APPENDIX Q	EXPERIMENTAL STUDY SCRIPT FOR FLIGHT 2	179
APPENDIX R	EXPERIMENTAL STUDY POST-ASSESSMENT 1	183
APPENDIX S	EXPERIMENTAL STUDY POST-ASSESSMENT 2	186
APPENDIX T	EXPERIMENTAL STUDY POST-ASSESSMENT 3	189
VITA		196

LIST OF TABLES

TABLE	Page
1.1	Classifications of Selected Unmanned Aerial Vehicles Currently in Operation 6
7.1	Descriptive Statistical Results for Object Identification Task Completion Time Between Interface Conditions. 71
7.2	Results of Statistical Difference of Means and Medians Tests Between Interface Conditions for Object Identification Task Completion Time. 75
7.3	Descriptive Statistical Results for Evaluation Task Completion Time Between Interface Conditions. 77
7.4	Results of Statistical Difference of Means and Medians Tests Between Interface Conditions for Evaluation Task Completion Time. 80
7.5	Descriptive Statistical Results for Image Capture Task Completion Time Between Interface Conditions. 82
7.6	Results of Statistical Difference of Means and Medians Tests Between Interface Conditions for Image Capture Task Completion Time. 86
7.7	Arithmetic Mean Results for Participant Heart Rate Between Interface Conditions. 88
7.8	Descriptive Statistical Results for Reported Role Empowerment Confidence Between Interface Conditions. 89
7.9	Descriptive Statistical Results for Reported Role Empowerment Comfort Between Interface Conditions. 90
7.10	Descriptive Statistical Results for Reported Best Individual and Team Performance Between Interface Conditions. 93
8.1	Correlation Findings Between Level of Command Experience and Reported Role Empowerment. 100
8.2	Correlation Findings Between Reported Responsibility for the Robot and Reported Role Empowerment. 101

LIST OF FIGURES

FIGURE	Page
1.1 A Micro UAS <i>Mission Specialist</i> (far right) Passively Shares an AirRobot® AR-100B Payload Camera Display with the <i>Pilot</i> (center). The Display (upper left) Contains Numerous Visual Indicators Such as Battery Voltage, Flight Time, Distance from Home, etc. that are Important to the <i>Pilot</i> but not the <i>Mission Specialist</i>	2
2.1 General Illustration of the Shared Roles Model for a Human-Robot Team . . .	14
3.1 Formulation of the the Shared Roles Model for mUAS that Focuses Only on the <i>Pilot</i> and <i>Mission Specialist</i> Roles and Represents the State of the Practice Where the <i>Mission Specialist</i> is a Passive Viewer of the <i>Pilot</i> Interface. The Blue Arrow Indicates Verbal Communication from the <i>Mission Specialist</i> to the <i>Pilot</i> for Payload Camera Control and Image Capture. The <i>Knowledge Worker</i> and <i>Flight Director</i> Roles are Excluded to Simplify Focus Toward the <i>Mission Specialist</i>	34
3.2 Interface Design Architecture for a <i>Mission Specialist</i> Interface for mUAS. . .	39
4.1 Touch-Based Gestures Afforded in the Role-Specific <i>Mission Specialist</i> Interface Design	42
5.1 Initial Implementation of the <i>Mission Specialist</i> Interface on an Apple® iPad. A Captured Image of the Simulated Train Derailment is Shown. The <i>Mission Specialist</i> Swipes (Up and Down) and Pinches (In and Out) Directly on the Video Display to Control the Payload Camera for Tilt (Up and Down) and Zoom (Out and In). Images are Captured by Pressing the Capture Image Button	45
5.2 Overhead Map of the Simulated Train Derailment at Disaster City® with the Three Waypoints Shown for Each Mission Trial. Mission Trial 1 Waypoints are Shown as Circles and Mission Trial 2 Waypoints are Shown as Squares. The Numbers Indicate the Three Waypoints in the Ascending Order They Were Visited	46
5.3 Refinements of the Role-Specific <i>Mission Specialist</i> Interface Informed by the Exploratory Study. A Captured Image of the Simulated Train Derailment is Shown. The <i>Mission Specialist</i> Swipes (Up and Down) and Pinches (In and Out) Directly on the Video Display to Control the Payload Camera for Tilt (Up and Down) and Zoom (Out and In). Images are Captured by Pressing the Capture Image Button. Additionally Added are Zoom and Tilt Indicators, an Overview Map, Position of the Robot, and a Digital Compass	57

FIGURE	Page
5.4 Shared Roles Model Representations of the <i>Mission Specialist</i> Interface Versions. (a) The Passive-Coordinated, Filtered Interface Permits Only Passive Viewing of the Filtered <i>Pilot</i> Display and Verbal Direction of the <i>Pilot</i> . (b) The Active-Coordinated, Filtered Interface Permits Only Direct Control of the Payload Camera and Limited Verbal Communication with the <i>Pilot</i> . (c) The Dual-Coordinated, Role-Specific Interface Permits Direct Control of the Payload Camera and Full Verbal Communication with the <i>Pilot</i> . Observed Contention for Payload Camera Control is Shown in Red	58
6.1 Frontal and Overhead Map Views of the Simulated Train Derailment at Disaster City® with the Three Waypoints Shown for Each Mission Trial. Mission Trial 1 Waypoints are Shown as Circles and Mission Trial 2 Waypoints are Shown as Squares. The Numbers Indicate the Three Waypoints in the Ascending Order They Were Visited	61
7.1 Empirical Cumulative Distribution Functions for Object Identification Task Completion Time by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Time Measurements ($n = 57$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Time Series. Red Circles Represent Dual-Coordinated, Role-Specific Time Measurements ($n = 51$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Time Series	73
7.2 Empirical Cumulative Distribution Functions for Object Identification Task Completion Frequency by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Frequency Measurements ($n = 57$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Frequency Series. Red Circles Represent Dual-Coordinated, Role-Specific Frequency Measurements ($n = 51$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Frequency Series. The Frequency Measurements are Displayed on a Logarithmic Scale	74
7.3 Empirical Cumulative Distribution Functions for Evaluation Task Completion Time by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Time Measurements ($n = 51$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Time Series. Red Circles Represent Dual-Coordinated, Role-Specific Time Measurements ($n = 47$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Time Series	78
7.4 Empirical Cumulative Distribution Functions for Evaluation Task Completion Frequency by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Frequency Measurements ($n = 51$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Frequency Series. Red Circles Represent Dual-Coordinated, Role-Specific Frequency Measurements ($n = 47$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Frequency Series. The Frequency Measurements are Displayed on a Logarithmic Scale	79

FIGURE	Page
7.5 Empirical Cumulative Distribution Functions for Image Capture Task Completion Time by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Time Measurements ($n = 49$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Time Series. Red Circles Represent Dual-Coordinated, Role-Specific Time Measurements ($n = 46$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Time Series	83
7.6 Empirical Cumulative Distribution Functions for Image Capture Task Completion Frequency by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Frequency Measurements ($n = 49$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Frequency Series. Red Circles Represent Dual-Coordinated, Role-Specific Frequency Measurements ($n = 46$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Frequency Series. The Frequency Measurements are Displayed on a Logarithmic Scale	84
8.1 Nine States of the Shared Roles Model Across Two Dimensions - Focused Visual Common Ground and <i>Mission Specialist</i> Control. The Rows Represent Level of Control from Passive (None), to Dual (Shared), to Active (Full). The Columns Represent Common Ground Focus of the Interface from Unfiltered (None), to Filtered (<i>Pilot-Only</i> Artifacts Removed), to Role-Specific (Additional <i>Mission Specialist-Only</i> Information Added)	102
E.1 Gestures Used During the Exploratory Study for Apple iPad® Control of the DraganFlyer™X6 Payload Camera	129
G.1 Image Captured by the DraganFlyer™ X6 Payload Camera Illustrating the View from Waypoint 1 on Flight 1	132
G.2 Image Captured by the DraganFlyer™X6 Payload Camera Illustrating the View from Waypoint 2 on Flight 1	133
G.3 Image Captured by the DraganFlyer™ X6 Payload Camera Illustrating the View from Waypoint 3 on Flight 1	134
H.1 Image Captured by the DraganFlyer™ X6 Payload Camera Illustrating the View from Waypoint 1 on Flight 2	135
H.2 Image Captured by the DraganFlyer™ X6 Payload Camera Illustrating the View from Waypoint 2 on Flight 2	136
H.3 Image Captured by the DraganFlyer™ X6 Payload Camera Illustrating the View from Waypoint 3 on Flight 2	137
N.1 Gestures Used During the Experimental Study for Apple iPad® Control of the AirRobot® AR-100B Payload Camera	172

FIGURE	Page
P.1 Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 1 on Flight 1	176
P.2 Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 2 on Flight 1	177
P.3 Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 3 on Flight 1	178
Q.1 Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 1 on Flight 2	179
Q.2 Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 2 on Flight 2	180
Q.3 Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 3 on Flight 2	181

1. INTRODUCTION

Unmanned aerial systems (UAS) have experienced significant technological advancement and permeation into a myriad of modern domains [1, 2], especially military and various search and rescue operations [3–6]. Several factors can be attributed to this trend in overall UAS operational integration, including human safety [7, 8], clandestine capabilities [9, 10], remote access [11, 12], and high spatial resolution information retrieval [13, 14].

All UAS operations involve a human-robot team [15–19] and thus require a knowledge of human-robot interaction (HRI) for better interfaces and for fundamental concerns such as reducing the human-robot ratio and team organizational complexity. For the purposes of this research, the UAS human-robot team is defined as the human personnel primarily responsible for UAS flight, navigation, and acquisition of mission-related information and will exclude consumers of information without direct control over the payload or platform (referred to as *Knowledge Workers* in [20]). As will be discussed in Section 1.3, human team members may be co-located with the unmanned aerial vehicle (UAV) or at a remote location, and, depending on the type of UAV and mission, can vary in number. Additionally, human team member spatial and functional roles may both overlap (Figure 1.1).

Human roles occur in all UAS but are not well documented in the research or trade literature, especially for micro UAS (mUAS). There has typically been strong research focus on the technical capabilities of UAVs rather than on the people charged with their operation. Consequently, the framework for understanding UAS has traditionally favored improvements in UAV technology rather than exploring and improving human factors. Advancements in UAV technology have certainly extended the operational capabilities of the human team, but there must be a concerted effort put forth to study the human element, which may logically have an impact on UAS performance. This can be accomplished through formal HRI studies that adopt proper experimental design and evaluation method-

This dissertation follows the style of *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews*.



Fig. 1.1. A Micro UAS *Mission Specialist* (far right) Passively Shares an AirRobot® AR-100B Payload Camera Display with the *Pilot* (center). The Display (upper left) Contains Numerous Visual Indicators Such as Battery Voltage, Flight Time, Distance from Home, etc. that are Important to the *Pilot* but not the *Mission Specialist* (Courtesy of Center for Robot-Assisted Search and Rescue).

ologies. Studies such as these will provide insight into the complete state of HRI and offer potential improvements for UAS.

This section begins with the primary and secondary research questions that are investigated through this dissertation work. Section 1.2 discusses the importance of the *Mission Specialist* role in mUAS and the need for investigating a role-specific *Mission Specialist* interface in the context of HRI. In Section 1.3 details are provided for a better operational understanding of UAVs. Section 1.4 discusses the motivation for human-robot team involvement in the CBRN (chemical, biological, radiological, nuclear) domain. The

contributions of this dissertation work are provided in Section 1.5. An outline for the organization of this dissertation work is given in Section 1.6.

1.1 Research Question

The primary research question this dissertation work addresses is:

What is an appropriate human-robot interface for the Mission Specialist human team member in a micro unmanned aerial system that increases individual role performance?

HRI research for micro (or any) UAS human team roles does not readily appear in the literature, presenting a challenge for designers and developers working with current and future unmanned systems. The HRI knowledge void becomes manifest as research efforts attempt to improve UAS capabilities by instead focusing on, among other things, reducing the human-robot crewing ratio through merging human team roles and increasing UAV autonomy [21–23], increasing the number of UAVs in a single UAS [24–26], and making UAS smaller, more mobile, and available to more diverse domains [27], without first understanding how human team roles are actually interacting. As Hobbs [28] points out, there have been no human factors analyses published on any mobile interfaces for any UAS. The present lack of HRI understanding inhibits researchable improvements in UAS capabilities - especially for mUAS - that may be possible by considering individual (and team) interactions within a UAS human-robot team.

The primary research question can be decomposed into the following three secondary research questions:

1. *What is the current state of human-robot interaction for the Mission Specialist role in existing micro unmanned aerial systems?* This question is addressed in Section 2 through a comprehensive review of the current research literature on three mUAS field studies, as well as an examination of the trade literature for commercially-available mUAS.

2. *Which aspects of human-robot interaction support the creation of a role-specific interface for the Mission Specialist role in a micro unmanned aerial system?* This question is addressed in Section 3 through an examination of the Shared Roles Model, and a synthesis of five recommended design guidelines for a *Mission Specialist* interface from the literature findings for mUAS.
3. *How does a role-specific interface for the Mission Specialist affect individual Mission Specialist role performance?* This question is addressed in Sections 5 and 6 through experimental field studies with 26 untrained CBRN experts; three hypotheses are evaluated to assess the effects of a role-specific *Mission Specialist* interface for a mUAS.

This dissertation work is a comprehensive investigation of the *Mission Specialist* role in a mUAS, an examination of existing interaction principles to support the development of a role-specific interface for the *Mission Specialist*, and an assessment of individual performance for the *Mission Specialist* when utilizing a role-specific interface. The application domain used for this investigation is CBRN. Results are expected to be applicable to supporting domains and related domains outside of CBRN, and may include: the military, law enforcement, and civil engineering. This work will benefit not only the HRI and CBRN communities, but also the larger science, engineering, and education communities.

1.2 Why Focus on the *Mission Specialist* Role

The *Mission Specialist* role of operating the sensor payload occurs in all UAS teams but is not well documented. The roles of the human team members have had to adapt to UAS technological advances, such as increased range and autonomy; this adaptation has generally been accomplished through improvements in both hardware and software interfaces [28]. Understanding how a human fulfills the *Mission Specialist* role through the lens of HRI is critical for investigating general HRI in UAS, reducing the human-robot crewing ratio, and improving the individual role and team performance. However, research

and development to improve the HRI experience of UAS interfaces has largely focused on UAS flight and navigation [29,30]. A HRI approach to support the acquisition of data and mission-related information remains historically less well developed [31], especially for mUAS [32], as does an understanding of the HRI aspects of the *Mission Specialist* as the human team member responsible for such acquisition [28].

1.3 Understanding Unmanned Aerial Vehicles

The exact composition of a UAS human-robot team has been postulated to depend largely on the complexity of the UAV [33]. In this work, though focus is limited to mUAS, it is necessarily cogent to the discussion to provide basic terminology descriptions of UAV categories that human team members may operate. A four group classification system is employed here: micro, small, medium altitude long endurance (MALE), and high altitude long endurance (HALE), which is consistent with the size categorization of the United States Air Force [34, 35], Army [36], and Navy and Marine Corps [37] (Table 1.1). It is noted that for the purposes of this discussion, focus is restricted to subsonic and suborbital UAVs.

1.3.1 Micro Unmanned Aerial Vehicles

The first group, and primary focus of this work, consists of micro UAVs. This category of vehicle represents the smallest physical size, operational range (distance of travel), altitude (elevation above ground or sea level), and endurance (time of operation) of all UAVs, and it is the vehicle type most commonly available for commercial and civilian operations, such as wilderness and urban search and rescue. Micro UAVs allow human team members, which are usually co-located, to remotely navigate and visualize information in environments where, for example, humans or other ground-based robots are not practical. UAVs in the micro category are traditionally of a rotor- or fixed-wing design.

Table 1.1
Classifications of Selected Unmanned Aerial Vehicles (UAVs) Currently in Operation¹.

Group	UAV Platform Name	Size ² [meters]	Weight ³ [kilograms]	Range [kilometers]	Altitude [kilometers]	Endurance [hours]
Micro	AirRobot AR100B®	1.0 × 1.0	0.2	0.5-1.4	0.9	0.2-0.5
	Aeryon Scout	0.8 × 0.8	0.3	3.1	0.5	0.2-0.3
	Draganflyer X6	0.9 × 0.9	0.5	0.5	2.4	0.2-0.3
Small	AeroVironment Raven®	1.1 × 1.3	0.2	10.0	4.6	1.3
	AAI Shadow 600	4.8 × 6.8	41.3	200	4.9	12-14
	Northrop Grumman Fire Scout	9.1 × 8.4	272	127	6.1	5-8
MALE	General Atomics Predator®	8.2 × 16.8	136-204	460	7.6	24
	TAI Anka	10.1 × 17.3	441	200	9.1	24
	IAI Heron 1	8.5 × 16.6	550	300	9.1	20-45
HALE	General Atomics Reaper®	11.0 × 20.1	386-1,361	5,926	15.2	30
	IAI Heron TP	14.0 × 26.0	1,000	7,408	13.7	36
	Northrop Grumman Global Hawk	14.5 × 39.9	1,361	22,772	18.3	36

¹ Maximum operational parameters are reported and referenced from manufacturer specification sheets - normal operational parameter values will usually be lower and domain dependent.

² Dimensions given are (length × wingspan)

³ The maximum payload weight the vehicle can carry

1.3.2 Other Unmanned Aerial Vehicles

Small UAVs expand upon the operational range, altitude, and endurance of the human-robot team without a significant change in the physical size of the vehicle. This would be important, for example, to on-site military combat units who will co-locate with the vehicle, but need to maintain a large displacement distance for reconnaissance operations. Increased levels of autonomy are also found in small UAVs. One of the main differences between micro and small UAVs, besides an improvement in operational characteristics, is

the dominance of fixed-wing vehicles and the increased payload weight capacity for small UAVs; very few rotor-based vehicles have been developed with small UAV (or higher) operational parameters.

The two larger two groups consist of MALE and HALE UAVs. MALE UAVs possess a several order of magnitude larger endurance than small UAVs. Consequently, the size of the MALE vehicles also dramatically increases. A tenable advantage to the increase in vehicle size is a significantly larger payload weight capacity, which may consist of not only reconnaissance sensor technology, but also the ability to transport and remotely deliver munitions to identified targets. MALE UAVs are typically not co-located with their primary human team members, as they may require more specialized service and maintenance, as well as more formal takeoff and landing areas. HALE UAVs represent the largest and most complex UAVs that have been developed to date. Most of the HALE UAVs mirror many of the operational characteristics of modern manned military aircraft in terms of their range, altitude, and endurance. The main difference between MALE and HALE UAVs, besides operational characteristics, is the size of the vehicle and, therefore, the increased payload weight capacity that HALE UAVs are capable of carrying.

1.4 Importance to CBRN

Human teams in the CBRN domain, robot-assisted or otherwise, are established to accomplish specified tasks and goals in response to natural or man-made disaster events. Typically, CBRN teams are instantiated by a supervisory emergency management effort or agency [38]. An example of a CBRN-related team deployment may include looking for survivors after a massive structural collapse [39]. Recovery efforts may also be included, for example, the inspection of potential property losses after massive destruction from a hurricane [18]. Human team participants must usually undergo specialized emergency responder training to be considered for inclusion on a CBRN team; participation therefore tends to be most common from fire and emergency rescue departments in local and

regional jurisdictions who would not usually have a great deal of experience interacting with robots.

The addition of a UAV to a CBRN team (forming a UAS human-robot team) can extend the visual capabilities of the team into disaster-affected locations that may be hazardous or unreachable for humans alone. Including the robot may require additional specialized training time for involved personnel, but it has the potential to expedite search, rescue, and/or recovery efforts [40]. Typically there are two types of UAV involved with CBRN. The first type of UAV used is a fixed-wing vehicle that allows for high search patterns, producing a plan view perspective for visual investigations. An example of a fixed-wing UAV would be the AeroVironment Raven®. The second type of UAV used is a quad-rotor vehicle that permits both high search patterns and forward-facing visual investigations due to the vertical takeoff and hover capabilities. An example of a quad-rotor vehicle would be the AirRobot® AR-100B. The selection of which type of UAV tends to be mission-specific; however, in this work, focus will be on a quad-rotor vehicle type due to the dual nature of its operational capabilities.

1.5 Contributions

Three primary contributions are proposed by this dissertation work to the fields of HRI and CBRN: i) the first focused HRI analysis and specification of the *Mission Specialist* role, ii) a new set of recommended design guidelines for, and an implementation of, a *Mission Specialist* interface that increases individual role performance, and iii) an empirical evaluation of the Shared Roles Model for identifying vulnerabilities in HRI with mUAS. For each contribution, specific impacts to both fields are characterized as scientific, economic, and social in nature. The three contributions and their respective impacts to the fields of HRI and CBRN are as follows.

1.5.1 First Focused Study of the *Mission Specialist* Role

This work presents the first focused study of the *Mission Specialist* role for mUAS; it is also the first of its kind for any UAS. The review of literature and synthesis of three human team roles provides scientific understanding for the current state of mUAS HRI. mUAS personnel requirements for CBRN may also be impacted in that the three human team roles could become codified in state and federal UAS operation regulations. The economic impacts for each of the two fields lay primarily with the human labor involved; knowing *a priori* how many human team roles will be necessary for mUAS operations will allow for proper economic planning and budgeting. Social impacts from the formal study of the *Mission Specialist* role also dually affect HRI and CBRN. Understanding that the current manner of *Mission Specialist* role interaction in mUAS may be suboptimal provides supporting evidence for an investigation of alternative pathways to improved role and team performance; optimality should necessarily influence response time for victim assistance and may help save more human lives and/or property.

1.5.2 New Guidelines for a *Mission Specialist* Interface

There are currently no published design guidelines for a *Mission Specialist* interface for mUAS (or any UAS). This work investigates HCI and HRI principles from the research literature and synthesizes five recommended design guidelines, giving a scientific framework for pursuing such an interface. The *Mission Specialist* interface is also an example of rapid prototyping that can easily be deployed for HRI field exercises in the domain of urban search and rescue. Economic impacts from this dissertation work include potential new employment opportunities for software engineers and developers, who will have access to the recommended design guidelines and interface software from which to propose new applications for HRI, as well as CBRN. The social impacts of this work will manifest through improvements in human-robot team interaction through the use of the *Mission Specialist* interface. Likewise, the view of the public and government officials towards

CBRN-related operations should improve as movement toward optimal performance typically creates positive perspectives towards publicly-funded projects.

1.5.3 Unique Empirical Evaluation of the Shared Roles Model

This work provides the first empirical evaluation of the Shared Roles Model for mUAS. Application of the Shared Roles Model will yield new scientific insight into identifying vulnerabilities in HRI with a mUAS human-robot team in the CBRN domain, and could lead to new ideas and approaches in Social Roles Theory. The economic impacts from the application of the Shared Roles Model would likely be an increase in the supply of highly-trained professionals who, through working on this project, can understand, research, and improve upon the Shared Roles Model and Social Roles Theory in general. By its very nature, the Shared Roles Model is social and will impact the efficiency of individual roles on the human-robot team, as well as other individual roles on similar human-robot teams that have not yet been investigated within the same modeling context. Other social impacts may manifest in the form of the full Shared Roles Model where *Knowledge Workers*, roles external to the actual human-robot team, gain benefit from the data collected during mission operations to inform and improve decision-making in a much larger context.

1.6 Organization of the Dissertation

This dissertation is organized as follows. Section 2 serves as a review of the research literature for factors associated with *Mission Specialist* HRI in mUAS. A brief overview of Joint Cognitive Systems and the Shared Roles Model, as a basis for characterizing human-robot teams, is provided. Presented next in Section 2 is a review of three HRI studies from the research literature that focus on mUAS; six commercial systems that have not been formally studied in the literature are reviewed as well. Finally in Section 2, interaction principles from both HCI and HRI applicable to mUAS are discussed. In Section 3, the theoretical foundations and approach for this dissertation work are given. The Shared

Roles Model is formulated for mUAS that includes two human team roles (*Pilot* and *Mission Specialist*) synthesized from the literature findings. Recommended design guidelines for a *Mission Specialist* interface, synthesized from the literature findings in Section 2.3, are given that provide for the construction of a system architecture. Section 4 describes the implementation of a *Mission Specialist* interface for a mUAS, including the hardware and software specifications. An exploratory field study for the *Mission Specialist* interface is given in Section 5. Section 6 presents the experimental methods and design to assess the effects of a *Mission Specialist* interface on individual role performance. An analysis of the experimental data and results is given in Section 7. Section 8 presents a discussion of the experimental results. The conclusions, including specific details for the main contributions of this dissertation work, and proposed future work are given in Section 9.

2. RELATED WORK

In this section, a literature review of factors relevant to understanding the HRI of a *Mission Specialist* role is given for mUAS. Human-robot team modeling is discussed, with a specific review of Joint Cognitive Systems and the Shared Roles Model for generic unmanned systems. Next, a review of three published mUAS field studies is given, as well as an additional review of commercially-available mUAS technology from the trade literature. Finally, eight sets of interaction principles are reviewed from both the HCI and HRI literature.

2.1 Human-Robot Team Models Related to Micro Unmanned Aerial Systems

There are several frameworks from which to model collaboration in human-robot teams [41]. For the case of mUAS, the Shared Roles Model (developed from Social Role Theory and described within the context of a Joint Cognitive System) provides an acceptable framework for human-robot team interaction as it was based on empirical unmanned systems studies [20]. The Shared Roles Model is a compromise between two polar opposite approaches - the Taskable Agent Model and the Remote Tool Model - emphasizing its ability to capture an appropriate balance of robot semi-autonomy and the connectivity needs of the human team [20].

2.1.1 Joint Cognitive Systems

The Shared Roles Model relies on the viewpoint of a human-robot team operating as a Joint Cognitive System (JCS). As described by Hollnagel and Woods [42], the focus of the JCS is on the co-agency of the participants rather than on the individual participants as distinct components. The *what* and *why* are emphasized in a JCS rather than the *how*. The JCS approach permits less restriction on formalized definition of the cognitive system itself, including functions and processes. This permits an easier description of robots as

agents or as artifacts and, more importantly, leads to the idea of the Shared Roles Model [20].

2.1.2 Shared Roles Model

The Shared Roles Model is a compromise between the Taskable Agent Model and the Remote Tool Model for describing human-robot teaming. In the case of the Taskable Agent Model, full autonomy of the robot is the goal of the system, with teleoperation being temporary in nature, if necessary at all. On the opposite end of the human-robot model spectrum is the Remote Tool Model. According to premises of the Remote Tool Model, the robot is essentially devoid of autonomy and used entirely as a tool by the human team. The Shared Roles Model is a hybrid approach that assumes robot semi-autonomy with improved human connectivity for communication [20].

In Murphy and Burke [20], the Shared Roles Model has six different types of primary agents, four shared roles (*Pilot-Platform Telefactor*, *Mission Specialist-Payload Telefactor*), and two singletons (*Safety Officer* and *Knowledge Worker*) (Figure 2.1). The *Mission Specialist* role primarily has an egocentric perspective through the UAV that is shared with the *Pilot* role. The *Pilot* role primarily has an exocentric perspective of the UAV that is shared with the *Mission Specialist* role. The *Safety Officer* and *Knowledge Worker* roles do not share either perspective. Information transfer can occur between the *Pilot* and *Mission Specialist* roles. Communication of mission directives can occur between the *Pilot* and *Knowledge Worker* roles. Similarly, transfer of data can occur between the *Mission Specialist* and *Knowledge Worker* roles. An important factor to consider in the Shared Roles Model is the potential latency of information transfer, whether it is data from the *Mission Specialist* role or communication of directives to and from the *Pilot* role. Results from the application of the Shared Roles Model must be hypothesis-driven due to the empirical nature of the model.

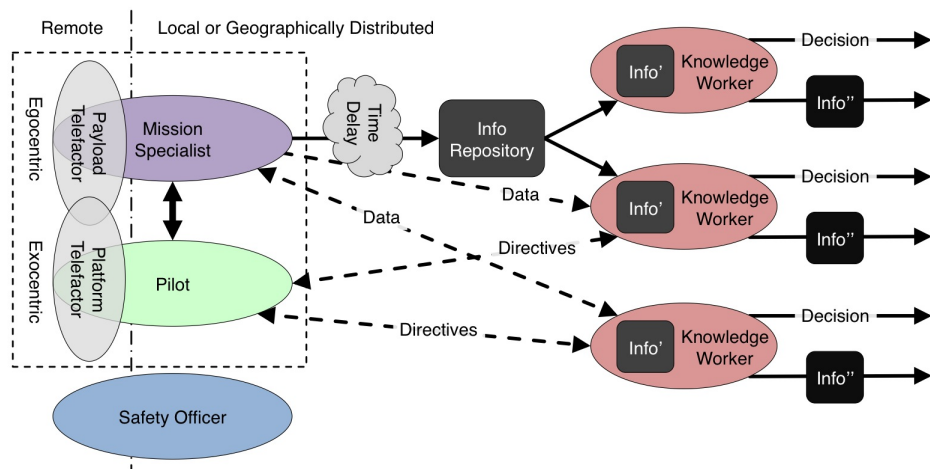


Fig. 2.1. General Illustration of the Shared Roles Model for a Human-Robot Team (From Murphy and Burke [20]).

2.2 Human-Robot Interaction Literature on Micro Unmanned Aerial Systems

In comparison to larger UAS [2, 6, 15, 16, 19, 22, 23, 30, 31, 43, 44], studies of mUAS HRI are the least well documented among all UAV categories, which may likely be due to the often non-domain-specific nature of use in mostly commercial and civilian applications. In this section, three mUAS studies are summarized from the research literature for insight into domain applications, human team roles, and the HRI technology involved. Additionally, commercially-available mUAS not formally studied in the research literature are summarized.

2.2.1 The Murphy 2008 Study

Murphy et al. [18] used a Like90 T-Rex rotary-wing micro UAV in order to survey damage in post-Hurricane Katrina and post-Hurricane Wilma operations. Three human team roles are described: *Flight Director*, *Pilot*, and *Mission Specialist*, as well as the interaction technology (radio control hardware and a heads-up display) used by the *Mission Specialist* role with the micro UAV.

2.2.1.1 Human-Robot Team Description

Murphy et al. [18] defined three human team roles: *Flight Director* (also denoted as the *Safety Officer*), *Pilot*, and *Mission Specialist* in the post-Hurricanes Katrina and Wilma missions. The *Flight Director* role was described as the individual responsible for overall safety of the team members (human and UAV). The *Flight Director* is in charge of mission situation awareness and has the authority to terminate the operation at any point. The role of a micro UAV *Pilot* defined by the Murphy study is the human team member responsible for teleoperating the vehicle within line-of-sight. They further indicate that the *Pilot* is responsible for the general airworthiness of the UAV prior to and during flight, and addresses maintenance issues of the vehicle. Finally, the Murphy study defines the role

of a micro UAV *Mission Specialist* as a single human team member solely in charge of the collecting reconnaissance data. Specific responsibilities include viewing the real-time video output from the UAV camera, directing the *Pilot* for reconnaissance, and adjusting the UAV camera settings for optimal image capture.

2.2.1.2 Interaction Technology Description

The *Mission Specialist* role observed the real-time video feed from the T-Rex UAV camera on a separate display screen and used independent radio control hardware for camera positioning. A second study described by Murphy et al. [18] during a separate post-Hurricane Katrina operation involved the use of an iSENSYS IP-3 rotary wing micro UAV. Here the *Mission Specialist* role wore a heads-up-display (HUD) for real-time visualization and utilized radio control hardware for positioning of the payload camera.

2.2.2 The Adams 2009 Study

In a study on goal-directed task analysis for wilderness search and rescue exercises that was based on prior field studies by Cooper and Goodrich [21], Adams et al. [5] defined three human team roles: *Incident Commander*, *Pilot*, and *Sensor Operator* and employed the use of experimental fixed-wing micro UAVs fitted with a gimbaled camera.

2.2.2.1 Human-Robot Team Description

The Adams study defined three human team roles: *Incident Commander*, *Pilot*, and *Sensor Operator* in their description of wilderness search and rescue exercises. The *Incident Commander* was characterized as having the unique role of managing the search and rescue effort. They describe the *Pilot* as the role responsible for both aviation and navigation. Finally, the Adams study defines the *Sensor Operator* as the human team

member role assigned the responsibility of directing a gimbaled camera on the micro UAV for scanning and imagery analysis.

2.2.2.2 Interaction Technology Description

The *Sensor Operator* role as described by Adams et al. [5] visualized the video feeds from the vehicle on a display screen and controlled the camera settings using independent radio control hardware.

2.2.3 The Oron-Gilad 2010 Study

Oron-Gilad and Minkov [45] provide two investigations of combat units utilizing a micro UAV during the Second Lebanon War of 2006. Four human team roles are described: (*Team Commander, Mission Commander, Field Operator, and Operator*), as well as the interaction technology (handheld touch screen with a keyboard, trackball, and joystick) used by the *Operator* role with the micro UAV.

2.2.3.1 Human-Robot Team Description

Oron-Gilad and Minkov [45] ethnographically describe four human team roles: *Team Commander, Mission Commander, Field Operator, and Operator*. A *Team Commander* role serves as the head of the human-robot team, and may communicate with other UAS human-robot teams in the field or control stations and, in addition, may monitor the technical condition of the vehicle. More complex situations described did arise requiring an additional individual, a *Mission Commander*, to join the team in order to focus only on strategy and coordination. Oron-Gilad and Minkov [45] provide detail on a *Field Operator* role that gives input as needed regarding where the vehicle should fly; however, this role appears to, at best, have limited flight control and navigation input capabilities. Finally, Oron-Gilad and Minkov describe an *Operator* role that is responsible for looking at

specific areas and targets to evaluate the occupancy status of enemy troops. In their study, the *Operator* focused on reconnaissance and the tactical aspects of the UAS mission.

2.2.3.2 Interaction Technology Description

Both studies presented by Oron-Gilad and Minkov indicated that the *Operator* role interacted with a handheld touch screen device. Additionally, there was a dedicated tablet laptop docked to the handheld device. The control panel had traditional hardware setup for interfacing, including a keyboard, trackball, and combination mouse/joystick. It was implied that both the *Pilot* and *Mission Specialist* roles had to share the same handheld device to interact with the vehicle.

2.2.4 Other Commercial Micro Unmanned Aerial Systems

Though not formally studied in the research literature, there are several commercially-available micro UAVs. User interaction with these vehicles ranges from simple hardware-based radio control to more sophisticated software-based control interfaces. Skybotix Technologies offers the CoaX[®], a coaxial helicopter capable of general surveillance through a fixed-mounted onboard camera. An open-source application programming interface (API) is available to allow for flight control customization by one or more team members; however, the onboard camera is not controllable [46]. The Parrot AR.Drone is a quad-rotor UAV that has both fixed forward- and vertical-facing cameras. An open-source API is also available. The AR.Drone is unique in that it is controllable only with Apple iOS devices [27].

Larger micro UAVs include the AirRobot[®] AR-100B, which is a quad-rotor micro UAV that includes an interchangeable payload. The *Pilot* for flight operations uses a hardware control interface that also contains a small display screen that can project real-time video when a camera is used as a payload. An API is available for the AirRobot[®] AR-100B for control (both flight and camera) customization; therefore a *Mission Specialist*

role could separately interact with the vehicle for data gathering purposes on a separate laptop device [47]. The DraganFlyer™ X series of rotor-based micro UAVs, produced by Draganfly Innovations, Inc., is controlled primarily by a hardware interface with limited touch screen interaction for flight and navigation. An onboard camera is also controllable using the same hardware interface, but video can be broadcast wirelessly to a HUD or a separate display station, thereby allowing a *Mission Specialist* role the ability to complete reconnaissance tasks [48]. Aeryon Labs has designed the Scout, a quad-rotor vehicle with a hot-swappable payload that may include a gimbaled camera. The Aeryon Scout is capable of beyond line-of-sight-operations and uses exclusively a touch-based software interface for flight and navigation control. Real-time video and image data transmission during the flight is available (to any wireless display device) and a *Mission Specialist* role could independently interact with the system to control the camera and complete reconnaissance tasks using a customized version of the touch screen interface [49].

2.3 Interaction Principles Applicable to Micro Unmanned Aerial Systems

Human-computer interaction (HCI) and HRI as design-focused areas in the field of human factors consider issues such as accessibility, awareness, and experience [50]. It is therefore necessary to consider a survey of interaction principles from both HCI and HRI, in order to gain insight and an interaction frame of reference for the investigation of a role-specific *Mission Specialist* interface.

2.3.1 Human-Computer Interaction Principles

At the most fundamental level, HCI is the study of people, computer technology, and the ways in which these two groups influence one another [51]. It is not enough to simply understand the technology, or the people; rather it is essential to understand both in the context of the work that is to be performed. There have been numerous publications over the years that attempt to present *the* guidelines that should be used throughout HCI. Not

surprisingly, there has not been one universal set of guidelines produced that has been widely adopted. However, from the literature that has been published it is possible to extract salient HCI principles that are applicable to the design of a *Mission Specialist* interface. In the following paragraphs, a survey of four fundamentally different approach areas to HCI design principles is presented including, where possible, a brief summary from each author for each principle.

The first set of HCI principles surveyed are from Schneiderman and Plaisant [52] and are based on over thirty years of HCI research, design, and testing across multiple domains. These principles represent a more general, common user-approach to user interface design in HCI. Schneiderman and Plaisant refer to their guidelines as the *Eight Golden Rules* for user interface design are as follows.

1. *Strive for consistency.* Consistent sequences of actions should be required in similar situations; identical terminology should be used in prompts, menus, and help screens; and consistent color, layout, capitalization, fonts, and so on should be employed throughout. Exceptions such as required confirmation of the delete command or no echoing of passwords, should be comprehensible and limited in number.
2. *Cater to universal usability.* Recognize the needs of diverse users and design for plasticity, facilitating transformation of content. Novice to expert differences, age ranges, disabilities, and technological diversity each enrich the spectrum of requirements that guides design. Adding features for novices, such as explanations, and feature for experts, such as shortcuts and faster pacing, can enrich the interface design and improve perceived system quality.
3. *Offer informative feedback.* For every user action, there should be a system feedback. For frequent and minor actions, the response can be modest, whereas for infrequent and major actions, the response should be more substantial. Visual presentation of the objects of interest provides a convenient environment for showing changes explicitly.

4. *Design dialogs to yield closure.* Sequences of actions should be organized into groups with a beginning, middle, and end. Informative feedback at the completion of a group of actions gives operators the satisfaction of accomplishment, a sense of relief, a signal to drop contingency plans from their minds, and an indicator to prepare for the next group of actions.
5. *Prevent errors.* As much as possible, design the system such that users cannot make serious errors. If a user makes an error, the interface should detect the error and offer simple, constructive, and specific instructions for recovery. Erroneous actions should leave the system state unchanged, or the interface should give instructions restoring the state.
6. *Permit easy reversal of actions.* As much as possible, actions should be reversible. This feature relieves anxiety, since the user knows that errors can be undone, and encourages exploration of unfamiliar options. The units of reversibility may be a single action, a data-entry task, or a complete group of actions.
7. *Support internal locus of control.* Experienced users strongly desire the sense that they are in charge of the interface and that the interface responds to their actions. They do not want surprises or changes in familiar behavior, and they are annoyed by tedious data-entry sequences, difficulty in obtaining necessary information, and inability to produce their desired result.
8. *Reduce short-term memory load.* Humans' limited capacity for information processing in short-term memory requires that designers avoid interfaces in which users must remember information from one screen and then use that information on another screen.

The next set of HCI principles surveyed are from Sharp et al. [53] and are largely based on the work of Norman [54]. These HCI design principles also represent a general

approach to user interface design, but focus specifically on interaction design. The five HCI design principles given by Sharp et al. are as follows.

1. *Visibility*. It is important that the methods of interaction for the user interface are visible and not hidden from the user. Additionally, the methods of interaction should not be arranged in an ambiguous or confusing manner. Highly visible controls that are intuitive to the user are ideal in design.
2. *Feedback*. The concepts of visibility and feedback are highly interconnected. Feedback should be provided to the user regarding what action has been undertaken and what goal has been accomplished. The decision as to what combinations of feedback are appropriate will depend on the activity, but will ultimately be essential in providing the correct level of interaction visibility to the user.
3. *Constraints*. The design concept of constraining refers to determining ways of restricting the kinds of user interaction that can take place at a given moment. This is usually manifest as a deactivation of certain visible methods of interaction because they are not relevant or available to the current activity.
4. *Consistency*. The term consistency refers to designing interfaces to have similar operations and use similar elements for achieving similar tasks. A consistent interface is one that follows a set of standardized rules. Consistent interfaces are easier to learn and use, and create an environment where users are less prone to making mistakes.
5. *Affordance*. The affordances of an interface refers to the attributes of objects that allow people to know how to use them. When the affordances of a physically-based object are perceptually obvious, it is easy to know its methods of interaction. Doing so make interaction easier for a user and reduces learning time for completing an action and goal.

Effective visualization of data in a concise format is important for many domain application designs, and especially for the design of a *Mission Specialist* interface. Few [55] suggests *Thirteen Common Mistakes in Dashboard Design* where, by definition, a dashboard is a single-screen display of the most essential information needed to perform a job. Dashboards are most common in business or financial domains, but the single-screen, highly-graphical wont of mobile devices make the principles of dashboard design cogent to this work. The thirteen design principles given by Few are as follows.

1. *Stay within the boundaries of a single screen.* A dashboard should confine its display to a single screen, with no need for scrolling or switching between multiple screens. This enables comparisons that lead to insights for the user that might not occur any other way. Fragmentation of any data into separate screens or single screen that require scrolling should be avoided.
2. *Supply adequate context for the data.* Providing context to displayed data is critical for user understanding. The amount of context that should be incorporated to enrich the measures on a dashboard depends on its purpose and the needs of its users. More context is not always better, but enough context is essential for providing a successful user interface experience.
3. *Avoid displaying excessive detail or precision.* Dashboards almost always require a fairly high-level of information to support the user's needs for a quick overview. Too much detail, or measures that are expressed too precisely, just slow users down without providing any real benefit to them. It is important to avoid having too much information rather than too little.
4. *Choose a deficient measure.* For a measure to be meaningful, it is necessary for the user to know what is being measured and the units in which the measure is being expressed. A measure is defined as deficient if it is not one that most clearly and efficiently communicates data meaning to the user.

5. *Choose appropriate display media.* Quantitative data should be represented in the most appropriate format available. Graphical representations should be used for easy visualization by the user, and should lead to straightforward comparison when more than one data source is to be examined.
6. *Introduce meaningful consistency.* The means of visual display should always be selected on the basis of what works best, even if the results in a dashboard are filled with nothing but the same instance of data representation. Users are not likely to be bored with consistency if they have the necessary information to do their jobs.
7. *Use well designed display media.* It is not enough to choose the right medium to display the data and its message - it is also necessary to design the components of the medium to communicate clearly and efficiently, without distraction. Use of color, layout, and scale are always important factors.
8. *Encode quantitative data accurately.* Graphical representations of quantitative data are sometimes mistakenly designed in ways that display inaccurate values. Scale plays an especially important role here, particularly when two or more data sets are compared within the same graphical representation.
9. *Arrange the data properly.* Dashboards often need to present a large amount of information in a limited amount of space. Information should be well organized, with appropriate placement based on importance and desired viewing sequence, and with a visual design that does not segregates data into fragmented or meaningless groups.
10. *Highlight important data effectively or not at all.* When a user looks at a dashboard, their eyes should be immediately drawn to the information that is most important, even when it does not reside in the most visually prominent areas of the screen. Since all data represented on a dashboard is in essence, important, highlighted emphasis should be activity specific.

11. *Keep the display free of clutter and useless decoration.* Even if users initially enjoy fancy decorations upon first sight, they will eventually grow weary of it in a few days. Static features that do not serve as a method of interaction should be kept small and visually subtle for the user.
12. *Appropriate use of color.* Color should not be use haphazardly. Choices in color should be made thoughtfully, with an understanding of how humans perceive color and the significance of color differences. Avoid using the same color in different sections of a dashboard because users are likely to assign meaning and comparison.
13. *Design an attractive visual display.* Most dashboards that have been designed are just plain ugly. When a dashboard is unattractive, the user is put in a frame of mind that is not conducive to its use. Care should be taken to display data in an attractive manner, without adding anything that distracts from or obscures it.

The final set of HCI principles surveyed are from Endsley et al. [56] and represent an approach to user-centered situation awareness design. Situation awareness, loosely defined here from Endsley et al. is the act of being aware of what is happening around you and understanding what that information means to you now and in the future. Situation awareness is decomposed into three levels: i) perception of the elements in the environment, ii) comprehension of the current situation, and iii) projection of future status. The eight HCI design principles given by Endsley et al. are as follows.

1. *Organize information around goals.* Information should be organized in terms of the user's major goals, rather than presenting it in a way that is technology-oriented. It should be organized so that the information needed for a particular goal is co-located and directly answers the major decisions associated with the goal.
2. *Present level 2 situation awareness information directly - support comprehension.* As attention and working memory are limited, the degree to which displays provide information that is processed and integrated in terms of Level 2 situation awareness requirements will positively impact situation awareness.

3. *Provide assistance for Level 3 situation awareness projections.* One of the most difficult and taxing parts of situation awareness is projection of future states of the system. System-generated support for projecting future events and states of the system should directly benefit Level 3 situation awareness, particularly for less experience users.
4. *Support global situation awareness.* A frequent problem for situation awareness occurs when attention is directed to a subset of information, and other important elements are not attended to. Designs that restrict access to information only contribute to attentional narrowing for a user.
5. *Support trade-offs between goal-driven and data-driven processing.* Designs need to take into consideration both top-down and bottom-up processing. The design of a system around user goals will support goal-driven processing, while the big picture display that supports global situation awareness will support data-driven processing by directing the user as to where to focus attention to achieve high-priority goals.
6. *Make critical cues for schema activation salient.* In that mental models and schemata are hypothesized to be key features used for achieving the higher levels of situation awareness in complex systems, the critical cues use for activating these mechanisms need to be determined and made salient in the interface design for a user.
7. *Take advantage of parallel processing capabilities.* The ability to share attention between multiple tasks and sources of information is important in any complex system. System designs that support parallel processing of information by the user should directly benefit situation awareness.
8. *Use information filtering carefully.* The problem of information overload in many systems must still be considered. The filtering of extraneous information not related to situation awareness needs, and reduction of data by processing and integrating

low-level data to arrive at situation awareness requirements, should be beneficial to situation awareness.

2.3.2 Human-Robot Interaction Principles

As with HCI principles, there also does not exist one universally-accepted set of HRI guidelines that have been widely adopted. Consequently, there are no formal HRI guidelines that address the design of a role-based interface for a mUAS human-robot team. However, a survey of the HRI literature does reveal different investigations for narrow aspects of HRI design such as goal-directed task analysis [57], task structure [58], and metrics of analysis [59]. In the following paragraphs, a survey of four different - but system-relevant - sets of design principles for HRI is presented including, where possible, a brief summary from each author for each principle.

The first set of HRI principles surveyed are from Goodrich and Olsen [60] and are based on previous studies of neglect tolerant autonomy and efficient interfaces. These principles represent a cognitive information processing approach to design in HRI. Goodrich and Olsen refer to their guidelines as the *Seven Principles of Efficient Human Robot Interaction* and are as follows.

1. *Implicitly switch interfaces and autonomy modes.* It is often desirable to change the way in which a user controls a robot and receives information about the robot. Such changes are sometimes mandated by the environment and sometimes made at the discretion of the human; which autonomy mode and interface elements are selected depends on the context established by the environment, communications channel, user, etc.
2. *Let the robot use natural human cues.* People have extensive experience in accomplishing tasks and in interacting with other people. With this experience comes a set of natural expressions. Natural language is an elusive goal but there are some

natural forms of expression that can be useful, such as pen-based computing and multi-touch interaction.

3. *Manipulate the world instead of the robot.* The purpose of interacting with a remote robot is to accomplish some task in the world. Insofar as is possible, robot artificial intelligence and interfaces should be designed so as to allow the task to be done, rather than drawing attention to the robot and the interface per se.
4. *Manipulate the relationship between the robot and the world.* It is sometimes difficult to develop interfaces and autonomy that directly supports world manipulation. Human attention may need to be drawn to the robot. Information regarding the status of the robot in relation to a goal state or information that relates robot pose to world coordinates is useful.
5. *Let people manipulate presented information.* One primary purpose of an interface is to present information, primarily about the world, the relationship between the world and the robot, and about the robot. When information is displayed to the user, the purpose of the information should be to support decision-making by the user.
6. *Externalize memory.* One primary difficulty with teleoperating a robot via camera perspective is that the user cannot see the robot's true point of view. To simplify the cognitive load resulting from projecting one's self into the perspective of the robot, memory should be externalized to help create a proper sense of self during operation.
7. *Help people manage attention.* Attention is a major bottleneck in cognitive information processing. Even if sufficient information is presented to a user, if their attention is not on this information than incorrect decisions can be made. Thus, it is important for a user to properly manage attention.

The second set of HRI principles surveyed are from Riley et al. [61]. These HRI principles represent situation awareness-oriented design guidelines for enhancing HRI. The five HRI design principles given by Riley et al. are as follows.

1. *Task/Mission factors.* Interface design must support the perceptual, cognitive, and physical demands imposed on the user by performance requirements as well as different mission parameters. Requirements for divided attention should be minimized and the human-robot ratio should be increased to facilitate higher levels of situation awareness.
2. *System factors.* Automation usage decisions must be guided by a user-centered design approach that emphasizes the goals of the human user, rather than the technology to be built. Automation must be tempered by consideration of the effects of different automation characteristics on user workload, situation awareness, and task performance.
3. *Environmental factors.* Well-designed user interfaces will enable users to maintain situation awareness for both their own local environment and the remote environment where the robot is located. When multiple robots or locations are involved, interfaces will also need to support user prioritization of environments and tasks through proper use of alerts and alarms.
4. *Individual and team factors.* Effective human-robot task performance is dependent upon each user's individual situation awareness, the team's overall situation awareness, and the team's joint situation awareness. Interfaces should be designed to flexibly adapt to individual differences in user innate ability, skill, and level of experience.
5. *External world and user interface design factors.* Other actors (humans, robots, targets, etc.), display characteristics, and control limitations interact with other HRI factors (task/mission, system, etc.) to influence user situation awareness. Negative

effects can be mitigated by designing interfaces that expressly address problems associated with control latency and information integration, whether purely visual or interactive in nature.

The third set of HRI principles surveyed are from Oron-Gilad and Minkov [45]. These principles were developed based on an ethnographic survey of soldiers operating a remotely-operated vehicle, and represent a bottom-up operational perspective. The six common design guidelines given by Oron-Gilad and Minkov are as follows.

1. *Modularity and flexibility.* The interface should fit and/or adapt to different mission properties. The user should be able to choose the most suitable configuration for a specific mission.
2. *Automation.* The users should focus on the main task, which is usually video interpretation and guiding troops. Automation tools and flexible level of automation selection can free users from the technical operation of the system when necessary.
3. *Training.* For simple tasks, operating UAV systems is feasible even when based on a short training period. Training efforts should focus more on mission implementation and not merely on the operation of the system.
4. *Customization.* Customization can sometimes contradict the need for short, effective training. Despite this, the ability to customize the user interface is beneficial specifically to active users.
5. *Display size.* The effect of display size depends on the task to be completed. A standard laptop PC with a display screen size of 14-inches is considered satisfactory for field-based applications, but weight and portability are primary concerns.
6. *Hand-held control device.* Hand-held control devices are a clearly needed for smaller UAS. The importance of hand-held devices that can be mounted or carried on a user's body in some way are ideal for mobile applications.

The final set of HRI principles surveyed are from Cooke and Chadwick [31]. The principles were lessons learned from human factors research on different UAVs. The six common design guidelines given by Cooke and Chadwick are as follows.

1. *Piloting a UAV is not exactly like flying a plane.* A human needs to navigate and control the position and speed of the vehicle. Landing and take-off are difficult tasks for both platforms. The visual display of a UAV pilot is very different and likened to looking at the world through a soda straw.
2. *The UAV needs to be integrated into the national airspace with other unmanned planes as well as manned planes.* Manned and unmanned air vehicles are anticipated to operate in the same airspace. This is true not only for military operations, but also for numerous civilian applications such as agricultural, border, and urban security surveillance.
3. *Automation is not the answer.* Automation changes the human's task to that of overseer, often removing the human from the system such that there is a loss of situation awareness when conflicts and errors arise. With automation, the task from a human's point of view can get even more difficult and error prone.
4. *Multiple UAV control can be difficult.* Ultimately, successful multi-vehicle control hinges on reliable automation that can work in concert with the human. Having automation that is not reliable may be worse than no automation at all. Multi-vehicle control is complicated and a simple increase in vehicle autonomy is not the solution.
5. *Human interaction is critical, yet challenging.* UAV operators can become spatially disoriented and have visual perception that is limited by the camera angle, and then exacerbated by being physically removed from the feedback of the vehicle. Thus, proper training and interface design to improve human interaction are warranted.
6. *Remote operation has implications for society.* There are social implications for civilian applications of UAVs. They range from privacy issues to attitudes associated

with suggesting that future passenger flights may be completely pilotless. Issues such as these should be considered for UAV integration into the national airspace.

2.4 Summary

This section provided a background overview for factors associated with *Mission Specialist* HRI in mUAS. Human-robot team theory and modeling were discussed in the context of a Joint Cognitive System. The general form of the Shared Roles Model was presented. Details of three HRI studies from the research literature, which included descriptions of the human-robot team and the interaction technology used, were given. Also provided were details on commercial mUAS that have not been formally studied in the literature. Finally, eight sets of interaction principles (from both human-computer interaction and human-robot interaction literature) applicable to mUAS were reviewed.

3. THEORY AND APPROACH

This section presents the theoretical foundations and approach for a *Mission Specialist* interface for mUAS. A formulation of the Shared Roles Model for mUAS is presented, including three formal human team roles synthesized from the literature (*Flight Director*, *Pilot*, and *Mission Specialist*). Three findings are developed from mUAS field studies literature that suggest a *Mission Specialist* role will require a small, mobile, and visual interface that is role-specific and software-based. Five recommended design guidelines are synthesized from a survey of current interaction principles, which result in a system architecture for a *Mission Specialist* interface for mUAS.

3.1 Shared Roles Model for a Micro Unmanned Aerial System

To formulate the Shared Roles Model for mUAS, the *Knowledge Worker* and *Flight Director* roles are excluded in order to simplify focus toward the *Mission Specialist* (Figure 3.1). Formal role labels in the model are defined in the following sections: *Pilot* and *Mission Specialist*. Payload and platform telefactors, representing egocentric and exocentric perspectives, respectively, remain consistent for this work. An interface is shown to illustrate the manner in which each human interacts with the micro UAV. Figure 3.1 represents the the state of the practice where the *Mission Specialist* is a passive viewer of the *Pilot* interface; verbal communication is from the *Mission Specialist* to the *Pilot* for payload camera control and image capture.

3.1.1 *Flight Director* Role Description

Proper supervisory planning, coordination, and control of any operation are critical to its success, especially for a mUAS human-robot team. Across the mUAS field studies literature, one or more human team member responsible for directing the mission was

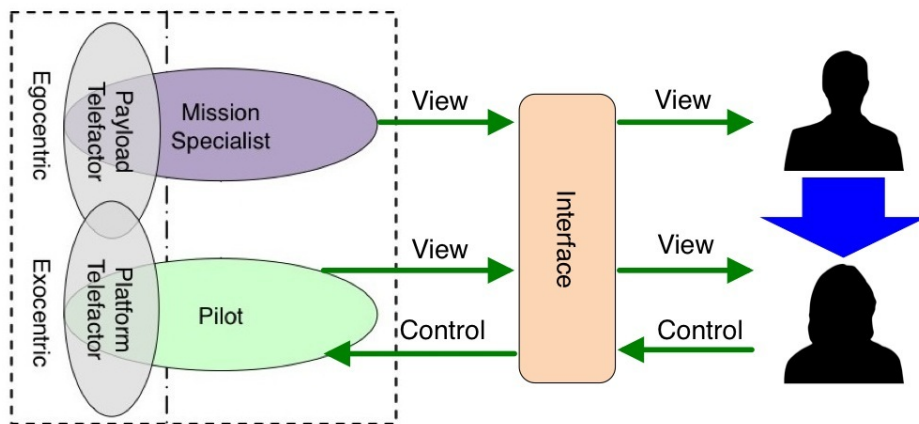


Fig. 3.1. Formulation of the the Shared Roles Model for mUAS that Focuses Only on the *Pilot* and *Mission Specialist* Roles and Represents the State of the Practice Where the *Mission Specialist* is a Passive Viewer of the *Pilot* Interface. The Blue Arrow Indicates Verbal Communication from the *Mission Specialist* to the *Pilot* for Payload Camera Control and Image Capture. The *Knowledge Worker* and *Flight Director* Roles are Excluded to Simplify Focus Toward the *Mission Specialist* (Formulated from Murphy and Burke [20]).

found to be a recurring role. For the Shared Roles Model in this work, this role will be referred to as the *Flight Director*.

3.1.2 Pilot Role Description

Piloting the UAV is an essential human role and common to all mUAS human-robot teams. However, the degree to which one or more individuals is solely responsible for flight control activity may vary; navigation responsibilities may also be included as a role responsibility. For the formulation of the Shared Roles Model for mUAS, this human team role will be referred to as the *Pilot*.

3.1.3 Mission Specialist Role Description

mUAS operational capabilities allow a human-robot team to insert themselves remotely for the main purposes of visual investigation and recording and, in more advanced vehicle systems, delivery of an onboard payload. It is therefore incumbent that one member of the human team be solely responsible for carrying out these kinds of activities. This role is referred to as the *Mission Specialist*.

3.2 Human-Robot Interaction Findings in Micro Unmanned Aerial Systems

In this section, an analysis is provided for interaction technology found for the *Mission Specialist* role across all mUAS and reviewed in Section 2.1.2. Three findings are given that suggest current *Mission Specialist* performance in mUAS may be suboptimal due to the sharing of a single *Pilot*-oriented interface or a reuse of the *Pilot* interface.

3.2.1 Small, Mobile, and Visual Displays

The interaction technology used by the *Mission Specialist* had the three primary characteristics: mobile, small, and visual. Mobility was observed in all of the interfaces that the

Mission Specialist interacted with. Handheld controllers that could be carried and handled by one individual were the most common form of interaction device. Inputs were accomplished by the *Mission Specialist* through interactions with small controls, most commonly isotonic joysticks and pushbuttons on the handheld controllers. Interactive feedback to the *Mission Specialist* was visual and took the form of small video displays, graphical menus, and real-time video.

3.2.2 Shared, Duplicate, or Passive Interaction

In the literature the *Mission Specialist* either shared the same interface with the *Pilot* role, was given a duplicate of the *Pilot* interface, or was a passive viewer. No UAV system in the literature had a role-specific *Mission Specialist* interface; however, the availability of API customization in commercial UAV systems does allow for that possibility. Given that the *Mission Specialist* is a unique human team role, a distinct or different modality of HCI technology from that of the *Pilot* would be expected. Therefore, existing interfaces, in general, do not support the functionality of the *Mission Specialist* role.

3.2.3 Lack of Software-Based Interfaces

A mUAS *Mission Specialist* is more likely to use a hardware interface than a software interface. The responsibility of the *Mission Specialist* is for data acquisition and, often, interpretation. The possibility for direct manipulation of the imagery for verification, including extracting single static images and a video series for real-time playback while the flight continued to be recorded, appeared present in only one [45] of the ten surveyed mUAS (the full extent of which, however, was not clear). It should also be noted that this interaction was accomplished through the UAV interface with the broadest array of available HCI technology (isotonic joystick, keyboard, mouse, trackball, pushbutton panel, and touch screen). Interpretation support (such as synthetic overlays) and other software initiated functions were present on five of the ten systems surveyed, but these

options were only commercially documented. These observations suggest that there is a heavily reliance on the hardware-oriented interaction by current *Mission Specialists*. Current HRI for the *Pilot*-oriented interfaces could be limiting the software capabilities that may improve *Mission Specialist* performance in mUAS missions.

3.3 Recommended Design Guidelines for a *Mission Specialist* Interface

Five recommended design guidelines were synthesized for a role-specific *Mission Specialist* interface for a mUAS from the survey of interaction principles given in Section 2.3. The five recommended design guidelines are as follows.

3.3.1 Design for Unary Interaction

A unary focus of interaction means that simple, singular aspects of interaction should be specifically considered in all aspects of the design for the *Mission Specialist* interface. This may take the form of having the visual display on a single screen, mapping gestures to control signals in a one-to-one manner, and never being more than one interaction away from any function that the interface is capable of providing.

3.3.2 Design for Adequate Data Context

Adequate context of any data streams that the *Mission Specialist* interface may be capable of handling should be provided. Elements of the interface display and the data contained within them should be clearly identified visually to the user, such as the primary video window, a map, or areas of archived image and video review - there should never exist any data ambiguity during interaction.

3.3.3 Design for Natural Human Interaction

There are many different modes of interaction for user interfaces - graphical, textural, written, haptics, etc. For a *Mission Specialist* interface that will be used in field conditions, the impetus of small and mobile form-factoring necessarily dictates users having haptics-based interaction since keyboards and other ancillary devices become peripheral premiums and could be difficult to use.

3.3.4 Design for Cueing and Communication

In the context of the Social Roles Model, a human-robot team must be able to appropriately cue and communicate among one another. This should be taken into account for the design of a *Mission Specialist* interface and may manifest as subtle alert messages when an image has been captured, or as other visual cues indicating that data is available or there is a message to be communicated within the team.

3.3.5 Design for Flexibility and Expansion

No good interface design is ever perfect or permanent. Great interface designs allow for flexibility towards the user as new information is discovered about humans and/or domains. Likewise, advances in technology always provide new leverages that can potentially improve existing user interaction. The ability to easily expand functionality will provide longevity to any *Mission Specialist* interface design.

3.4 System Architecture for a *Mission Specialist* Interface

An interface design architecture based on the five recommended design guidelines synthesized for a *Mission Specialist* interface (see Section 3.3) is given in Figure 3.2. The *Mission Specialist* has two modes of interaction with the interface: i) viewing of the real-time data coming from the UAV, and ii) sending control signals to the payload camera. Control

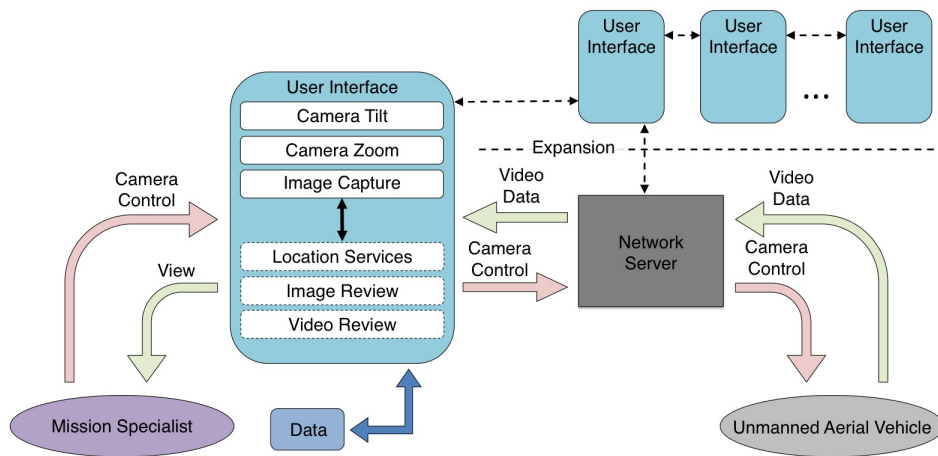


Fig. 3.2. Interface Design Architecture for a *Mission Specialist* Interface for mUAS.

signals include camera tilt, zoom, and image capture. Likewise, the UAV transmits real-time video and receives camera control signals. Communication is done wirelessly and through a central network server. Data is stored on the local interface device. Additional features of location-based services, static image review, and video review could also be integrated but will not be individually evaluated in this work. Additional expansion of the interface technology could include multiple co- or remotely-located *Mission Specialist* interfaces networked together to form a common space of interaction, and could possibly include other roles such as the *Pilot*.

3.5 Summary

This section discussed the theory and approach for the design of a *Mission Specialist* interface for mUAS. The Shared Roles Model was formulated for mUAS. Three formal human-robot team roles were synthesized from the literature for use in the Shared Roles Model: *Flight Director*, *Pilot*, and *Mission Specialist*. Five recommended design guidelines, based on a synthesis of interaction principles from the human-computer and human-robot interaction literature, were given. A system architecture was created, based on the five recommended design guidelines, for a *Mission Specialist* interface.

4. IMPLEMENTATION

The *Mission Specialist* interface with system architecture as described in Section 3.4 was implemented on an Apple® iPad device. Programming of the interface was accomplished using both the Objective-C and standard C programming languages. Additional open-source static C libraries that provide networking and real-time video processing capabilities were used.

4.1 Hardware Platform Description

There are several mobile devices available on the current market. Two of the more capable devices types for input and visualization are mobile tablets (e.g. Apple® iPad, Samsung Galaxy) and tablet PCs (e.g., Lenovo Thinkpad X200 Tablet, Dell Latitude XT2). Mobile tablets are typically 10-inches or smaller in screen size and resemble slate-based tablet PCs in terms of their form-factor; they are usually similar to smartphones (e.g., Apple® iPhone or Motorola Droid X) with regard to their operating systems (iOS and Android). Tablet PCs are larger and resemble the operational characteristics of normal laptops, including size and operating system. Based on the hardware platforms available, the Apple® iPad was selected for this work.

The Apple® iPad platform was selected for this work due to its mobility, unique multi-touch interface, and ability to provide a usable display in outdoor conditions. The Apple® iPad hardware affords three important touch-based gestures that can be customized and used for designing an interface: swipes, pinches, and taps (Figure 4.1). For control of the payload camera by the *Mission Specialist* interface, swipe up and down gestures will proportionally control the up and down tilt of the camera, in and out pinch gestures will proportionally control the zoom in and zoom out of the camera, and finger tap gestures will control button functionality (e.g., capture an image). Each of these gestures represents a natural and intuitive manner of interaction with the payload camera.

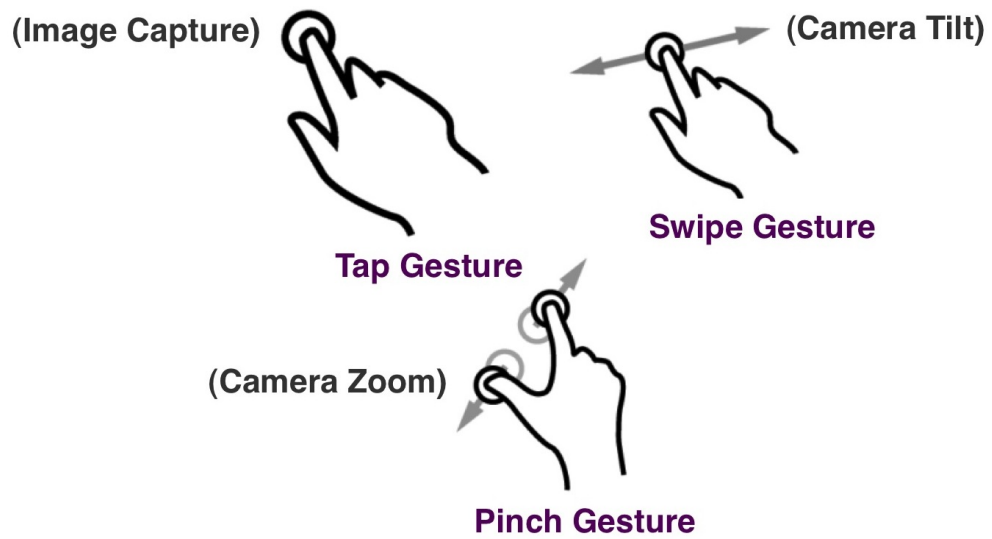


Fig. 4.1. Touch-Based Gestures Afforded in the Role-Specific *Mission Specialist* Interface Design (Adapted from GestureWorks.com).

4.2 Software Platform Description

The programming language that the Apple® iPad uses is Objective-C; however, much of the non-interface programming (e.g., network connectivity, etc.) was done using standard C with open-source static libraries. The *Mission Specialist* interface communicates wirelessly through an *ad hoc* network to a dedicated C-based server socket on a laptop computer running Microsoft Windows XP that is connected to the UAV base stations. This manner of connectivity was a requirement of the AirRobot® AR-100B and DraganFlyer™ X6 platforms but, due to the server software being written in standard C, could easily be adapted to other robot platforms that may support a different operating system (e.g., Linux or OSX). Real-time imagery from the payload camera is streamed to the *Mission Specialist* interface using a compiled static library version of Willow Garage's OpenCV software [62].

4.3 Summary

This section described the implementation of a *Mission Specialist* interface for a mUAS. The implementation was based on set of five recommended design guidelines and a system architecture established in Section 3. Detailed descriptions of the Apple® iPad platform and its software programming language and interaction capabilities were given.

5. EXPLORATORY STUDY

This section describes the overview, participants, measurements, results, and observations from an exploratory study of the *Mission Specialist* interface. The study consisted of 16 untrained responders that were CBRN experts, but had no mUAS experience, each participating in two different UAS mission trials to visually evaluate and capture images of a train derailment incident involving hazardous materials. Four types of measurements (performance, biophysical, survey, and audio/video) were recorded for each participant. Observations from the study suggested that with refinements, a *Mission Specialist* interface could be a useful tool for further studies to explore the HRI of individual *Mission Specialist* role performance in a mUAS.

5.1 Overview

The purpose of the exploratory study was to i) field test the *Mission Specialist* interface (Figure 5.1) within the context of actual mUAS missions and ii) explore the types of measurable interactions exhibited by the *Mission Specialist*. All of the exploratory study mission trials took place at the Disaster City® facility located on the campus of Texas A&M University. The context of the mission was a simulated train derailment involving hazardous materials, which is representative of the CBRN domain.

A 16 participant mixed-model study design was developed from the HRI study guidelines in [63]. The number of participants was chosen based on a power analysis to attain power equal to 0.80 in a single group measures design at an alpha equal to 0.05, given an estimate of mean correlation for repeated measures of 0.80. Each participant made two different UAV flights - one per mission trial - with each flight having three pre-defined stationary waypoints and corresponding sets of questions regarding the identification of certain objects (e.g., identify any punctures or ruptures in the tanker truck and capture an image of each you may identify) (Figure 5.2). The maximum duration of the flights were limited to 7-minutes for consistency. The order of the interfaces (conditions) was random-



Fig. 5.1. Initial Implementation of the *Mission Specialist* Interface on an Apple® iPad. A Captured Image of the Simulated Train Derailment is Shown. The *Mission Specialist* Swipes (Up and Down) and Pinches (In and Out) Directly on the Video Display to Control the Payload Camera for Tilt (Up and Down) and Zoom (Out and In). Images are Captured by Pressing the Capture Image Button (Courtesy of Center for Robot-Assisted Search and Rescue).



Fig. 5.2. Overhead Map of the Simulated Train Derailment at Disaster City® with the Three Waypoints Shown for Each Mission Trial. Mission Trial 1 Waypoints are Shown as Circles and Mission Trial 2 Waypoints are Shown as Squares. The Numbers Indicate the Three Waypoints in the Ascending Order They Were Visited (Courtesy of Center for Robot-Assisted Search and Rescue).

ized to counterbalance the study. Participants were not given any formal hands-on training with the interfaces.

During condition 1, half of the participants viewed a passive video feed from the *Pilot* display on a laptop and instructed the *Pilot* to control the payload camera and capture images. The laptop was placed on the DraganFlyer™ X6 base station and adjusted for optimal viewing by each participant. Participants were given a verbal protocol from which

they could issue the following camera control instructions to the *Pilot*: tilt camera up, tilt camera down, zoom camera in, zoom camera out, and take photo. The second half of the participants used the *Mission Specialist* interface to actively control the camera and capture images. The Apple® iPad was placed on a camera stand that was adjusted for optimal viewing and interaction by each participant. Each participant in condition 2 used the interface they did not have in condition 1. For both flights, participants were given a verbal protocol from which they could issue the following UAV control instructions to the *Pilot*: turn left --degrees and turn right --degrees. The verbal protocol for UAV control was made available to participants since the DraganFlyer™ X6 platform camera mount cannot turn left or right.

The DraganFlyer™ X6 platform was used during the exploratory study. A professional pilot with extensive experience operating the vehicle served in the *Pilot* role for all of the mission trials. The *Pilot* was instructed to only follow the verbal commands issued by participants regarding camera and UAV control and to not anticipate the intentions of the participants.

5.2 Participants

Participants were selected primarily for their experience as specialized responders from CBRN in coordination with the Texas Engineering Extension Service (TEEX). Detailed demographic information about each participant was collected through a pre-assessment survey consisting of 18 questions. Of the 16 participants, 14 were men and 2 were women. Age ranges were: 25-years to 34-years (1 participant), 35-years to 44-years (2 participants), 45-years to 54-years (10 participants), and 55-years and older (3 participants). Each of the participants had prior experience with a mobile touch-based device (e.g., Apple® iPhone or iPad), with frequency of use from several times per week to continuously, for a period of at least one year. The types of interactions participants had with their mobile touch-based devices were: use it as a phone (all participants), check email (15 participants), surf the Internet (14 participants), and play games (7 participants). A majority of

the participants had previously used a Tablet PC or other pen-based device (e.g., Palm PDA) but indicated only short-term and/or infrequent usage. There were 9 participants who had prior experience controlling a remote camera either on a robot or through the Internet. Each of the participants, except one, had played a major role in actual CBRN-related missions. Two participants had been involved with a robot-assisted search and rescue mission (CBRN-related), which was reported as an exercise.

5.3 Measurements

There were four different types of measurements taken during the exploratory study: i) the number of completed tasks, ii) written post-assessment surveys, iii) biophysical measurements, and iv) audio/video recordings. Details for each type of measurement are as follows.

5.3.1 Task Completion

Task completion was measured by the number of images a participant captured during each mission trial. Images captured when using the *Mission Specialist* interface were saved on both the Apple® iPad and the payload camera. When participants passively viewed the video feed and instructed the *Pilot* to capture an image, resulting images were stored only on the payload camera. All images were time-stamped so they could be correctly associated with the corresponding participant and mission trial.

5.3.2 Post-Assessment Surveys

Post-assessment surveys to evaluate role empowerment (confidence and comfort) as reported by the participant in the *Mission Specialist* role were given. The post-assessment survey consisted of two parts of 10 questions each, and was given after each mission trial (i.e., a post-assessment survey after using the passive-coordinated interface, and a

post-assessment survey after using the active-coordinated interface - each with identical questions but in the context of the interface used). Responses addressed confidence and comfort in interface actions as measured on a standard 5-point Likert scale.

5.3.3 Biophysical

Participant heart rate was recorded during both mission trials. Biopack BioNomadix® sensors were used for wireless recording and were placed on the non-dominant hand of each participant. Prior to the set of mission trials, each participant was asked which hand they would swipe a mobile device with and the sensor was placed on the opposite hand indicated. Active recording status was verified before and throughout each mission trial.

5.3.4 Audio and Video

Four high-definition GoPro® cameras were used for recording audio and video. The first camera was mounted on a hard hat that each participant wore to provide a first-person perspective. The second camera was mounted on the stand that held the Apple® iPad to provide a view of each participant when they interacted with the *Mission Specialist* interface. The third camera was mounted to the top of the laptop to provide a view of each participant when they viewed the mirrored display from the *Pilot*. A final camera was placed approximately 20-feet behind the participants to capture an overall view of the study. Video from the UAV was also recorded. All cameras were calibrated before each mission trial to ensure a correct field of view.

5.4 Results

The *Mission Specialist* interface was successfully used in 16 mUAS mission trials. Measurement data were collected for task completion, levels of stress, and role empowerment. A between \times within analysis of variance (ANOVA) was used to analyze the results

from the mixed-factor design study to determine if there was a significant effect between participants and/or within participants, based on the order the participants used the two interface types and the interface type used.

5.4.1 Number of Completed Tasks

The mixed-model design for number of completed tasks consisted of the between participants factor being the number of captured and the within participants factor being the number of captured images per interface type. These two completed task variables were measured by reviewing the number of captured images on the payload camera for each condition. The interaction of which interface was presented first was also examined for its impact.

The between participants analysis results ($F[1,14] = 0.32, p = 0.58$) indicated there was not an effect of order in which the interfaces were presented. This result would suggest the participants are likely to perform a similar number of completed tasks regardless of the order in which they used the interfaces. The within participants analysis results ($F[1,14] = 12.04, p = 0.004$) suggest there is significant interaction within participants based on the number of images captured on the mission trials and based on the type of interface used.

Image capture statistics were examined to determine the significance of the within participants analysis results. Participants on average captured more images on both mission trials when using the passive approach ($M = 6.63, SD = 3.01$) than they did using the *Mission Specialist* interface ($M = 3.88, SD = 2.33$). On mission trial 1 when participants used the passive approach, more images were captured ($M = 6.75, SD = 2.66$) than when using the *Mission Specialist* interface ($M = 4.63, SD = 2.26$). On mission trial 2, participants using the passive approach captured more images ($M = 6.50, SD = 3.51$) than when using the *Mission Specialist* interface ($M = 3.13, SD = 2.30$). These results suggest that mission trial 1 ($M = 4.94, SD = 2.56$) and mission trial 2 ($M = 5.56, SD = 1.33$) had, on average, a difference of less than one captured image. There is also an average of less than a difference of one captured image based on which interface was first used.

5.4.2 Levels of Stress

The level of stress consisted of the within participant factor being the average heart rate (in beats per minute) per interface type. This biophysical variable was measured by averaging the heart rate data of each participant for each condition. The interaction of which interface was presented first was also examined for its impact. All heart rate results were determined to be non-significant.

5.4.3 Role Empowerment

The mixed-model design for role empowerment (confidence and comfort) consisted of the between participants factor being the average 5-point Likert confidence score and the within participants factor being the average 5-point Likert confidence score per interface type. These two survey variables were measured by averaging the post-assessment survey data of each participant for each condition. The interaction of which interface was presented first was also examined for its impact.

The between participants analysis results ($F[1,14] = 1.48, p = 0.24$) indicated there was not an effect of order in which the interfaces were presented. This result suggests the participants are likely to experience similar role empowerment regardless of the order in which they used the interfaces. The within participants analysis results ($F[1,14] = 14.35, p = 0.002$) suggest there is significant interaction within participants based on reported role empowerment for the mission trials and the order in which the interfaces were presented.

Post-assessment survey statistics were examined to determine the significance of the within participants analysis results. Participants on average reported more role empowerment regardless of mission trial when using the passive approach ($M = 4.53, SD = 0.80$) than they did using the *Mission Specialist* interface ($M = 3.56, SD = 1.07$). On mission trial 1 when participants used the passive approach, more role empowerment was reported ($M = 4.33, SD = 0.96$) than when using the *Mission Specialist* interface ($M = 3.84, SD = 0.97$). On mission trial 2, participants using the passive approach reported more role

empowerment ($M = 4.73$, $SD = 0.59$) than when using the *Mission Specialist* interface ($M = 3.28$, $SD = 1.16$). These results suggest that mission trial 1 ($M = 3.80$, $SD = 0.74$) and mission trial 2 ($M = 4.28$, $SD = 0.63$) had, on average, less than one half confidence rating point difference. There is also an average of less than one confidence rating point difference based on which interface was first used.

5.5 Observations

An analysis of the exploratory study results for the *Mission Specialist* interface resulted in five observations: viewing only a shared display and instructing the *Pilot* tended to result in more captured images, well-defined identification and image capture tasks resulted in similar results using both interfaces, similar levels of stress are experienced with both interfaces, similar visual feedback confusion was experienced using both interfaces, and more positive role empowerment was reported for the passive approach. These observations suggested that with refinements, a *Mission Specialist* interface could be a useful tool for further exploring role performance in mUAS.

5.5.1 More Captured Images with Passive Display

Participants captured more images when viewing a passive display and instructing the *Pilot* to control the payload camera and capture images. During the study, though time was emphasized as a limiting factor (i.e., 7-minute maximum flight time) and participants were asked only to capture a representative image, there was no penalty associated with capturing additional images. This led to multiple instances where participants using the passive approach directed the *Pilot* to perform exploratory 360-degree rotations of the UAV in order to capture several different images surrounding the train derailment. A similar observation did not occur with the *Mission Specialist* interface where participants were more focused on controlling the payload camera. This difference could be due to the

fact that giving instructions requires less effort of the participant, though it results in more action being taken by the *Pilot*.

5.5.2 Similar Captured Images for Well-Defined Tasks

For identification and image capture tasks that were well-defined, participants provided satisfactory responses and captured images in a similar manner when using both interface approaches. Well-defined tasks included reading and capturing images of various numbers printed on train cars and identifying punctures, ruptures, and vents on an overturned tanker truck. For tasks that were not well-defined, participants captured more representative images when viewing the passive display and instructing the *Pilot* to control the payload camera. Identification and image capture tasks that were not well-defined included identifying any hazardous product flows or possible exposure hazards associated with the derailment.

5.5.3 Similar Levels of Stress

Participants experienced a similar level of stress as measured by average heart rate for both interfaces. The *Mission Specialist* interface was not observed to induce any more stress than the passive approach. Each of the participants had been trained as a specialized emergency responder to work in high-stress situations; therefore, as realistic as the simulated train derailment was, it may not have fully replicated the conditions for which they are uniquely trained. Additionally, both types of interfaces used in the mission trial conditions represented a new experience to each of the participants, thus the non-significant level of stress recorded may have reflected the general lack of familiarity with both of the interface technologies.

5.5.4 Lack of Adequate Visual Feedback

Participants experienced a lack of adequate visual feedback when using both interface approaches. In both interface cases, each participant experienced at least one instance of difficulty with establishing payload camera status (i.e., extent of zoom or degree of tilt). For example, participants would attempt to zoom the payload camera in when the camera was already at maximum zoom. This suggests that payload camera status feedback should be provided visually to the *Mission Specialist* even though this feedback is not presently available to the *Pilot*. This is especially important if the *Mission Specialist* is a member of an *ad hoc* human-robot team and does not have training similar to that of the *Pilot*.

5.5.5 Greater Role Empowerment with Passive Display

Participants reported more positive role empowerment when viewing a passive display and instructing the *Pilot* to control the payload camera and capture images. Since role empowerment was reported as confidence in the ability to execute tasks with each interface, a possible cause of lower role empowerment may be latency. Each of the participants experienced some degree of latency in the payload camera controls when using the *Mission Specialist* interface. This was due in part to the technical limitations of an older UAV platform that was used for the study and may not be present in newer or different platforms. Conversely, the proprietary *Pilot* controls allowed for faster and smoother operation of the payload camera. If the control scheme for the *Pilot* could be better adapted to software-based control for a active-coordinated *Mission Specialist* interface, the latency issue would be likely be resolved.

5.6 Recommendations

Through an evaluation of the exploratory study observations, verbal participant feedback, and discussions with other specialized emergency responders at TEEX, regarding

the *Mission Specialist* interface, there were three recommendations for refinements and future studies: deeper focus on occupational expertise and role empowerment, more visual feedback is necessary on the interface, and UAV platform latency must be reduced. Refinements of the interface necessitate more precise interface terminology, which is described as active, passive, or dual.

5.6.1 Deeper Focus on Role Empowerment

Participant occupational experience and personality were minimally examined during the exploratory study. Additionally, there was no summative post-assessment survey instrument given in the exploratory study that compared both interface methods (only formative post-assessments after each interface condition). An examination of participant pre-assessment reporting found that most of the participants currently hold, or have held, more senior supervisory positions. This may suggest that in their current or prior roles as supervisors, participants may be more comfortable issuing directives (i.e., capture an image) than doing technical tasks themselves. A more appropriate approach to participant selection would be to ensure a broad range of command- and non-command-level experience in the participant pool. Likewise, a summative assessment after both interface conditions are complete to assess role empowerment at a task-level resolution may provide insight into why participants perform in a particular manner with each interface condition.

5.6.2 More Visual Feedback on Interface

An inadequate level of visual feedback for the *Mission Specialist* interface was reported by all of the participants in the exploratory study. This became especially apparent when the robot encountered poor wind conditions (greater than 10-miles per hour) and began pitching backwards and forward, which would often interfere with payload camera tilt inputs (i.e., it was unclear to the participants that they were over or under tilting). Zoom was also found to be an issue in both interface conditions as all of the participants. In the

case of the *Mission Specialist* interface condition, participants would often try to zoom in or out when the camera was at maximum zoom. This was also observed in the passive interface condition when they asked the *Pilot* for additional zoom when the payload camera was already at a maximum. Final recommendations from the exploratory study for refinements to the *Mission Specialist* interface are to include payload camera tilt and zoom indicators, an overview map, compass, and real-time position of the robot (Figure 5.3). The addition of the role focused information to the interface effectively focused the visual common ground for the *Mission Specialist*.

5.6.3 Reduce UAV Platform Latency

Each of the participants in the exploratory study experienced some degree of latency in the payload camera controls when using the *Mission Specialist* interface. This was due in part to the technical limitations of an older UAV platform that was used for the study and may not be present in newer or different platforms. Similar to the trend observed for the number of captured images, the command-level of experience present in each of the participants may have resulted in latency driving them to be more confident to issue instructions to the *Pilot* role. In future studies, it is recommended that any payload camera latency be minimized in order to provide an adequate evaluation experience.

5.7 Interface Terminology Precision

With the refinements to the *Mission Specialist* interface resulting in a third version, it is appropriate to consider more precise terminology to define the method of interaction which can also be visualized with the Shared Roles Model (Figure 5.4). When a *Mission Specialist* is only passively viewing a filtered video feed and instructing the *Pilot* for payload camera control and image capture, this is referred to as a passive-coordinated, filtered interface (Figure 5.4a). The *Mission Specialist* interface in the exploratory study is considered to be active-coordinated, filtered (Figure 5.4b) since it permits only direct control of



Fig. 5.3. Refinements of the Role-Specific *Mission Specialist* Interface Informed by the Exploratory Study. A Captured Image of the Simulated Train Derailment is Shown. The *Mission Specialist* Swipes (Up and Down) and Pinches (In and Out) Directly on the Video Display to Control the Payload Camera for Tilt (Up and Down) and Zoom (Out and In). Images are Captured by Pressing the Capture Image Button. Additionally Added are Zoom and Tilt Indicators, an Overview Map, Position of the Robot, and a Digital Compass (Courtesy of Center for Robot-Assisted Search and Rescue).

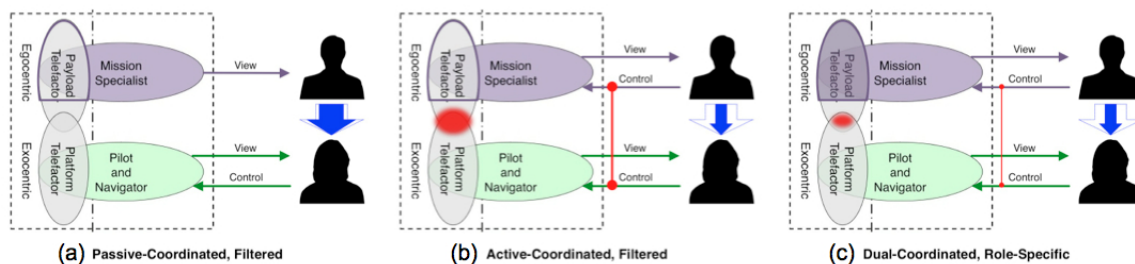


Fig. 5.4. Shared Roles Model Representations of the *Mission Specialist* Interface Versions. (a) The Passive-Coordinated, Filtered Interface Permits Only Passive Viewing of the Filtered *Pilot* Display and Verbal Direction of the *Pilot*. (b) The Active-Coordinated, Filtered Interface Permits Only Direct Control of the Payload Camera and Limited Verbal Communication with the *Pilot*. (c) The Dual-Coordinated, Role-Specific Interface Permits Direct Control of the Payload Camera and Full Verbal Communication with the *Pilot*. Observed Contention for Payload Camera Control is Shown in Red (Courtesy of Center for Robot-Assisted Search and Rescue).

the payload camera and little verbal communication with the *Pilot*. The refinements to the *Mission Specialist* interface combined with the option to verbally coordinate payload camera control and image capture with the *Pilot* identify it as a dual-coordinated, role-specific interface (Figure 5.4c). These more precise interface descriptions will be used throughout the remainder of this paper.

5.8 Summary

To summarize, this exploratory study for a mUAS *Mission Specialist* provided observations that when using a role focused interface *fewer images were captured, well-defined tasks resulted in a similar number of images captured, similar levels of stress were experienced, adequate visual feedback was not experienced, and less positive role empowerment was reported* by the *Mission Specialist* than when viewing a mirrored display and instructing the *Pilot*. The fewer number of images captured when the *Mission Specialist*

used the role focused interface may depend on the cost associated with capturing images, which the exploratory study did not adequately address. More specifically, the amount of effort required to complete a task was not considered and may negatively impact the *Pilot* role. Well-defined tasks resulted in a similar number of correct identifications and images captured with both interfaces. Future studies should focus on well-defined tasks for the evaluation of interfaces. The levels of stress experienced by a *Mission Specialist* are expected to be similar, regardless of the type of interface used, and may depend on the training of the participant. An actual train derailment scenario (i.e., an ethnographic study) may result in different or higher levels of stress experienced by similar participants. A lack of adequate visual feedback was experienced by all participants in this study. Future interfaces should incorporate visual feedback indicators for the payload camera status even though this information may not be accessible to the *Pilot*. Less positive role empowerment was reported when using the *Mission Specialist* interface, which was likely due to latency in the controls that were used. Removing this confound may result in greater levels of confidence for users of a *Mission Specialist* interface.

6. EXPERIMENTAL METHODS AND DESIGN

This section presents the experimental methodology and design for assessing the use of a role-specific *Mission Specialist* interface for mUAS. Three hypotheses are outlined (with expected findings) that were empirically used to answer the primary research question given in Section 1.1. Details of the experiment are given, including those for participants, facilities, equipment, and personnel. Assessment of the participants is discussed, including pre- and post-assessment surveys, as well as the metrics for measuring individual *Mission Specialist* performance. The study protocol and contingency plan for this investigation are also provided in this section.

6.1 Study Overview

A 10 participant mixed-model experimental study was conducted at the Disaster City® facility at Texas A&M in the context of a simulated train derailment involving hazardous materials. Each participant received interface instructions and participated in a 5-minute training flight prior to each interface condition. Two different UAV flights were made, one per mission trial, with each flight having three pre-defined stationary waypoints (Figure 6.1); participants completed activities and answered questions at each waypoint, consisting of object identification, evaluation, and capturing images. The maximum duration of the flights were limited to 10-minutes for consistency and participants were instructed that their goal was to capture images for all of the questions at all of the waypoints within this period of time. The order of the interfaces (conditions) was randomized to counterbalance the study. An AirRobot® AR100-B UAV was used in the experimental study.

During condition 1, half of the participants used the passive-coordinated, filtered interface on an Apple® iPad and instructed the *Pilot* to control the payload camera and capture images. Participants were given a verbal protocol from which they could issue the following camera control instructions to the *Pilot*: tilt camera up, tilt camera down, turn camera left, turn camera right, zoom camera in, zoom camera out, and take photo. The second half



Fig. 6.1. Frontal and Overhead Map Views of the Simulated Train Derailment at Disaster City® with the Three Waypoints Shown for Each Mission Trial. Mission Trial 1 Waypoints are Shown as Circles and Mission Trial 2 Waypoints are Shown as Squares. The Numbers Indicate the Three Waypoints in the Ascending Order They Were Visited (Courtesy of Center for Robot-Assisted Search and Rescue).

of the participants used the dual-coordinated, role-specific interface to control the camera and capture images (Figure 5.3). Participants could additionally, at any time, provide the same verbal commands to the *Pilot* that were available for the passive-coordinated, filtered interface condition. Each participant in condition 2 used the interface they did not have in condition 1.

6.2 Research Hypotheses and Expected Findings

There were three hypotheses and expected findings for the formal evaluation of a role-specified interface for the *Mission Specialist* human team member role that assesses affects on individual *Mission Specialist* role performance. The hypotheses address task role empowerment, task completion time, and levels of stress.

6.2.1 Same or Less Task Completion Time

Hypothesis 1 proposed that a *Mission Specialist* using a dual-coordinated, role-specific interface will complete tasks at the same speed or faster, as measured by the time it takes to complete assigned tasks. It was expected that the *Mission Specialist* would complete tasks faster having shared control of the payload camera with the *Pilot*.

6.2.2 Same or Less Stress

Hypothesis 2 proposed that a *Mission Specialist* using a dual-coordinated, role-specific interface will experience the same or less stress, as measured by the biophysical parameter heart rate. It was expected that the *Mission Specialist* role would experience less stress during the completion of a mission due to greater spatial and functional flexibility that the dedicated interface should provide.

6.2.3 Same or Greater Role Empowerment

Hypothesis 3 proposed that a *Mission Specialist* using a dual-coordinated, role-specific interface will report the same or greater role empowerment (confidence and comfort) as indicated through a post-assessment survey. It was expected that a *Mission Specialist* role would be more empowered in their role with direct control of the payload camera and the ability to verbally coordinate with the *Pilot*.

6.3 Participants

Participants were selected primarily for their experience as specialized CBRN responders in coordination with the Texas Engineering Extension Service (TEEX). Detailed demographic information about each participant was collected through a pre-assessment survey consisting of 36 questions (Appendix M).

Of the 10 participants, all were men. Age ranges were: 35-years to 44-years (3 participants), 45-years to 54-years (4 participants), and 55-years and older (3 participants). Eight of the participants had prior experience with a mobile touch-based device (e.g., Apple iPhone® or iPad®), with frequency of use from several times per week to continuously, for a period of at least one year. Two of the participants had no prior experience with mobile touch-based devices. The types of interactions participants had with their mobile touch-based devices were: use it as a phone (8 participants), check email (7 participants), surf the Internet (6 participants), and play games (5 participants). A majority of the participants had previously used a Tablet PC or other pen-based device (e.g., Palm PDA) but indicated only short-term and/or infrequent usage. There were 6 participants who had prior experience controlling a remote camera either on a robot or through the Internet. Eight of the participants had played a major role in actual search and rescue missions or exercises. Only three participants had been involved with a robot-assisted search and rescue missions or exercises. Six of the participants had command-level experience (e.g., Fire Captain, EMS Team Leader) and four had non-command-level experience (e.g., HAZMAT technician, Equipment Specialist). Nine of the participants were scored as having non-dominant personalities (one participant scored as having a dominant personality). Nine of the participants were scored as introverts (one participants scored as being an extrovert). All of the participants scored as having a high internal locus of control.

6.4 Facilities

All of the experimental trials took place at the Disaster City® facility, located on the Texas A&M campus, within the context of a chemical train derailment incident involving hazardous materials. Disaster City® has a collection of mockup buildings and various transportation infrastructure, forming an urban-like community that is capable of re-creating full-scale, collapsed structural disasters. The goal of these models is to simulate a wide array of disasters and wreckage that may be experienced by an urban search and rescue team. Disaster City® is one of the most comprehensive specialized emer-

gency response personnel training facilities available in the United States and provided ideal conditions for this experiment.

6.5 Equipment

Nine different pieces of equipment were used for this experiment. An AirRobot® AR-100B UAV, discussed in Section 2.2.4, was used for the robot role. As discussed in Section 4.1, the Apple® iPad was used as the role-specific *Mission Specialist* interface. One additional Apple® iPad was also kept onsite as a backup device. A Lenovo Thinkpad X200 Tablet PC was used as the network server acting between the AirRobot® AR-100B base station and the Apple® iPad. To provide the necessary wireless network connectivity between the Apple® iPad and the network server, an Apple AirPort Extreme device with 802.11n capabilities was used. For biometric sensing of the *Mission Specialist* role, wearable Biopack® BioNomadix sensors were used. Finally, three video and audio feeds were recorded by two external stationary and one first-person helmet GoPro high-definition cameras. Any additional equipment (e.g., power, cables, etc.) were included as needed for the primary equipment.

6.6 Personnel

The investigator of this work was primarily responsible for setting up experimental protocols and running all of the trials, and for analysis of the results. One trained *Pilot* role flew the AirRobot® AR-100B UAV. One trained *Flight Director*, although not included in the formal modeling, served as *Safety Officer* to ensure the safety of the human team during each mission trial.

6.7 Pre-Assessment Survey

An IRB-approved pre-assessment survey of individual background knowledge, experience, and personality was given to each participant (e.g., experiences with HRI, remote search and rescue video equipment, etc.) to ensure that were not, for example, all experts or all novices with mobile interface technology of the proposed type. These results were summarized for the participants in Section 6.3. Appendix M provides the 36 pre-assessment survey questions for each participant in this study.

6.8 Experimental Design

Measuring individual *Mission Specialist* performance was the primary focus of the experimental design. Individual performance measures included task completion time, heart rate (stress), and role empowerment (confidence and comfort). Based on the guidelines given in [63], the experiment consisted of a within-subjects trial that included 10 expert participants. Each participant made two UAV flights per trial (a total of 20 UAV flights). The original number of participants was chosen as 16 and was based on a power analysis to attain power equal to 0.80 in a single group measures design at an alpha equal to 0.05, given an estimate of mean correlation for repeated measures of 0.80. However, due to participant scheduling limitations, poor weather, robot availability, and facilities availability, there were only 10 participants who successfully completed the experiments.

6.9 Measuring *Mission Specialist* Performance

The main aspect of the experimental design was the performance evaluation of the *Mission Specialist* role individually using the role-specific interface, which was examined during the train derailment incident involving hazardous materials. The dual-coordinated, role-specific interface was compared with the passive-coordinated method where the *Mis-*

mission Specialist passively views a filtered display from the *Pilot* role and instructs the *Pilot* how to control the payload camera.

Direct measurement of individual *Mission Specialist* performance consisted of i) time to complete tasks, and ii) heart rate measurements (stress). Each high fidelity UAS mission flight required the *Mission Specialist* participant to identify and capture imagery of a series of features from the UAV video feed.

The time it took to complete assigned tasks was measured as the difference between the time the experimenter asked a question (or gave a directive), and the time the participant responds accordingly. There were three task categories (object identification, evaluation, and image capture). The time (in milliseconds) was used to evaluate the participant interacting with the both interface conditions for each task type category. Biophysical measurements, which included heart rate, for each participant were monitored to assess stress levels during the mission trials of the *Mission Specialist* role. Therefore, Hypotheses 1 and 2 were addressed using the direct measures (see Sections 6.2.1 and 6.2.2).

6.10 Post-Assessment Survey

An IRB-approved summative post-assessment survey to evaluate role empowerment (confidence and comfort) as experienced by the participant in the *Mission Specialist* role was given. The summative post-assessment survey consisted of 19 questions, and was given after both interface conditions were completed. Standard statistical results were developed based on the data from the post-assessment survey and were used to answer Hypothesis 1 that deals with role empowerment (see Section 6.2.3). Appendix T provides the 19 post-assessment survey questions for each participant in this study.

6.11 Study Protocol

For each potential participant in the experiment, an IRB-approved announcement for the study was read aloud by the investigator (see Appendix A). The verbal announcement

began with an introduction of the investigator and presented an overview of the study for individuals who may choose to participate. A contingency for individuals who did not wish to participate (at any time) in the experiment was given. A copy of the IRB-approved Information Form was then distributed for examination by the potential participants. Finally, potential participants completed the IRB-approved Consent Form. Upon consent, the potential participants became participants.

After formal consent has been given by each participant, an IRB-approved mission scenario script was then read to each participant (see Appendix F). Depending on which type of display a participant was to use (mirrored or dedicated - and assigned accordingly to prevent confounding), a summary of the specific mission was read. In either interface condition case, participants were instructed on acquiring imagery of targets, and on their roles and communication capabilities with the *Pilot* role, as well as with the investigator. After the mission scenario script had been read to each participant, questions were solicited by the investigator and then each experimental trial began. A 5-minute test flight was given to each participant prior to the main flight to gain familiarity with the interface and to reduce learning effects.

6.12 Contingency Plan

The principal contingency issue that did arise during the course of this work was the availability of participants for the experiment. As indicated in 6.3, all of the *Mission Specialist* participants were specialized response personnel. The contingency plan for this study was to leave participation open to other qualified individuals that may include, just as an example, student members of the Texas A&M Corps of Cadets. However, this additional participant pool was not pursued since it was desired to maintain a homogenous pool of specialized responders. The investigator coordinated any participant involvement through the appropriate channels at TEEEX and CRASAR.

6.13 Summary

This section described the details for assessing the effects of a dual-coordinated, role-specific *Mission Specialist* interface on individual *Mission Specialist* role performance. Three hypotheses with expected findings were outlined to answer the primary research question. Participant, facility, equipment, and personnel details were given. Descriptions of the participant surveys and the experimental design to assess individual *Mission Specialist* performance appear. Finally, a protocol and contingency plan for the study were given that permit a reproducible plan for other investigators.

7. DATA ANALYSIS AND RESULTS

This section presents the analyses for data collected during the experimental field study to evaluate the appropriate human-robot interface (passive-coordinated, filtered versus dual-coordinated, role-specific) that increases individual role performance for a *Mission Specialist* in a mUAS. Only a subset of the video and post-assessment survey data collected were analyzed for this dissertation as focus was restricted to individual *Mission Specialist* role performance; individual performance of the *Pilot* role and the actual performance and process of the team were not considered. The analyses performed for the experimental field study data included three categories: i) task completion time (object identification, evaluation, and image capture), ii) levels of stress (heart rate), and iii) role empowerment (confidence, comfort, and perceived best individual and team performance). For each of the three analyses, descriptive and inferential statistics are presented.

7.1 Task Completion Time Analyses and Results

This section presents the data analyses performed for the three task completion time categories (object identification, evaluation, image capture) for the two different interface conditions (passive-coordinated, filtered versus dual-coordinated, role-specific). Descriptive and inferential statistical results are provided for the task completion time categories.

Descriptive statistical analyses were performed using MATLAB® for all task completion time data in each of the three task completion time categories. The descriptive statistical analyses consisted of calculating the arithmetic mean (AM), standard deviation (SD), geometric mean (GM), geometric standard deviation (GSD), median (M), skewness (s), and kurtosis (k) for each task completion time category. Sauro and Lewis [64] have shown that the geometric mean is the best population center estimator to report for usability time studies involving less than 26 participants; this work followed that recommendation for reporting.

Inferential statistical analyses were performed using MATLAB® for all task completion time data in each of the three task completion time categories. The task completion time distribution type for each interface condition was determined by analyzing each empirical cumulative distribution function (eCDF) using the non-parametric Lilliefors and Jarque-Bera tests for goodness-of-fit. Normality was additionally examined using normal quantile plot correlation. The values reported for the Lilliefors test are the Kolmogorov-Smirnov KS test statistic, critical value (cv_L), and statistical significance (p -value). The JB test statistic, critical value (cv_{JB}), and statistical significance (p -value) were reported for the Jarque-Bera test. Normal quantile plot correlation was reported as a correlation coefficient (r_{qp}). Equivalence of variances between interface condition eCDFs was determined using the two-sample F test. Results of the equivalence of variances F -test are reported as an F -statistic, numerator degrees of freedom (df_n), denominator degrees of freedom (df_d), and statistical significance (p -value). Equivalence of means between interface conditions was determined using Welch's t -test. Results for Welch's t -test were reported as a t -statistic (t) with associated degrees-of-freedom (df), and statistical significance (p -value). Equivalence of medians between interface conditions was determined using the Wilcoxon rank sum test. The Wilcoxon test results were reported as a p -value indicating the statistical significance. All statistical tests were performed at a significance level (α) of 0.05.

7.1.1 Object Identification Tasks

The descriptive and inferential statistical results for object identification task completion time by interface condition are given in this section. Object identification task completion time results were found not to be statistically significantly different between the two interface conditions; therefore, a *Mission Specialist* using either the passive-coordinated, filtered or the dual-coordinated, role-specific interface completed object identification tasks in a similar amount of time. Object identification task completion time data

Table 7.1
Descriptive Statistical Results for Object Identification Task Completion
Time Between Interface Conditions.

Descriptive Statistic¹	Passive-Coordinated, Filtered	Dual-Coordinated, Role-Specific
Arithmetic Mean (<i>AM</i>)	15.0	11.0
Standard Deviation (<i>SD</i>)	19.3	16.6
Geometric Mean (<i>GM</i>)	5.8	3.3
Geometric Standard Deviation (<i>GSD</i>)	4.8	5.7
Median (<i>M</i>)	7.2	3.8
Skewness (<i>s</i>)	2.0	2.6
Kurtosis (<i>k</i>)	7.3	10.7

¹ Each descriptive statistic is reported in units of seconds except for skewness and kurtosis which are dimensionless quantities.

for both interface conditions were shown to follow a log-normal distribution with equal variances.

7.1.1.1 Descriptive Statistical Analyses for Object Identification Task Completion Time

Descriptive statistics for object identification task completion time are shown in Table 7.1. Object identification task completion when using the dual-coordinated, role-specific interface condition was determined to occur arithmetically faster ($AM = 11.0$ -seconds, $SD = 16.6$ -seconds) than object identification task completion when using the passive-coordinated, filtered interface condition ($AM = 15.0$ -seconds, $SD = 19.3$ -seconds). The dual-coordinated, role-specific interface condition was geometrically faster ($GM = 3.3$ -seconds, $GSD = 5.7$ -seconds) than the passive-coordinated, filtered interface condition ($GM = 5.8$ -seconds, $GSD = 4.8$ -seconds). The median object identification completion time was faster for the dual-coordinated, role-specific condition ($M = 3.8$ -seconds) ver-

sus the passive-coordinated, filtered condition ($M = 7.2$ -seconds). The dual-coordinated, role-specific interface condition had positive skewness ($s = 2.6$) and was leptokurtic ($k = 10.7$); the passive-coordinated, filtered interface condition had similar results ($s = 2.0$, $k = 10.7$). Considering geometric mean as the primary measure for object identification task completion, identifying objects when using the dual-coordinated, role-specific interface was accomplished, on average, 2.5-seconds (or 1.8 times) faster than when using the passive-coordinated, filtered interface.

7.1.1.2 Inferential Statistical Analyses for Object Identification Task Completion Time

Object identification task completion time-based eCDFs were developed for each interface condition (Figure 7.1). A line of best fit was determined for each object identification task completion eCDF time series. For the passive-coordinated, filtered and dual-coordinated, role-specific time-based eCDFs, the determined lines of best fit are given by Equation 7.1 ($R^2 = 0.985$) and Equation 7.2 ($R^2 = 0.984$), respectively:

$$P = 0.183 \ln(t) + 0.180 \quad (7.1)$$

$$P = 0.164 \ln(t) + 0.302 \quad (7.2)$$

where P is the eCDF probability and t is object identification task completion time in seconds. A frequency-based representation for each object identification task completion eCDF is shown in Figure 7.2 to provide an alternative view of object identification task completion speed. As can be observed in Figure 7.2, the dual-coordinated, role-specific interface appears to result in faster object identification task completion.

A visual inspection of Figures 7.1 and 7.2 and the determination of the lines of best fit suggested the object identification task completion time eCDF data follow a log-normal distribution; therefore, the time series data were log transformed and tested for normality.

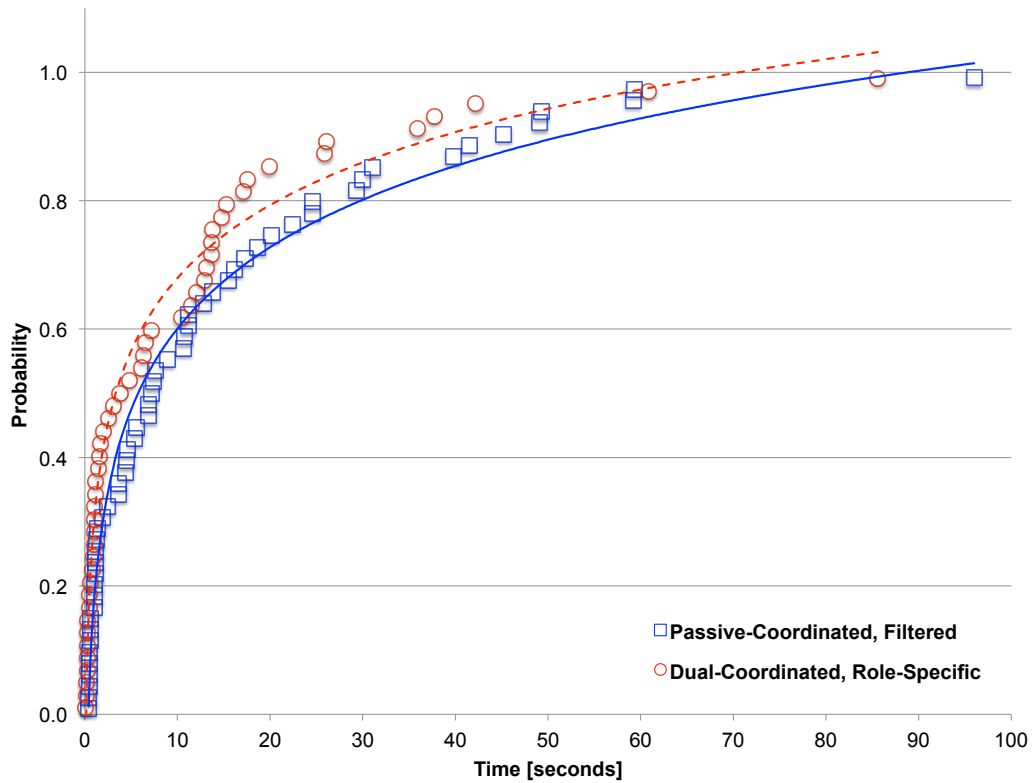


Fig. 7.1. Empirical Cumulative Distribution Functions for Object Identification Task Completion Time by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Time Measurements ($n = 57$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Time Series. Red Circles Represent Dual-Coordinated, Role-Specific Time Measurements ($n = 51$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Time Series.

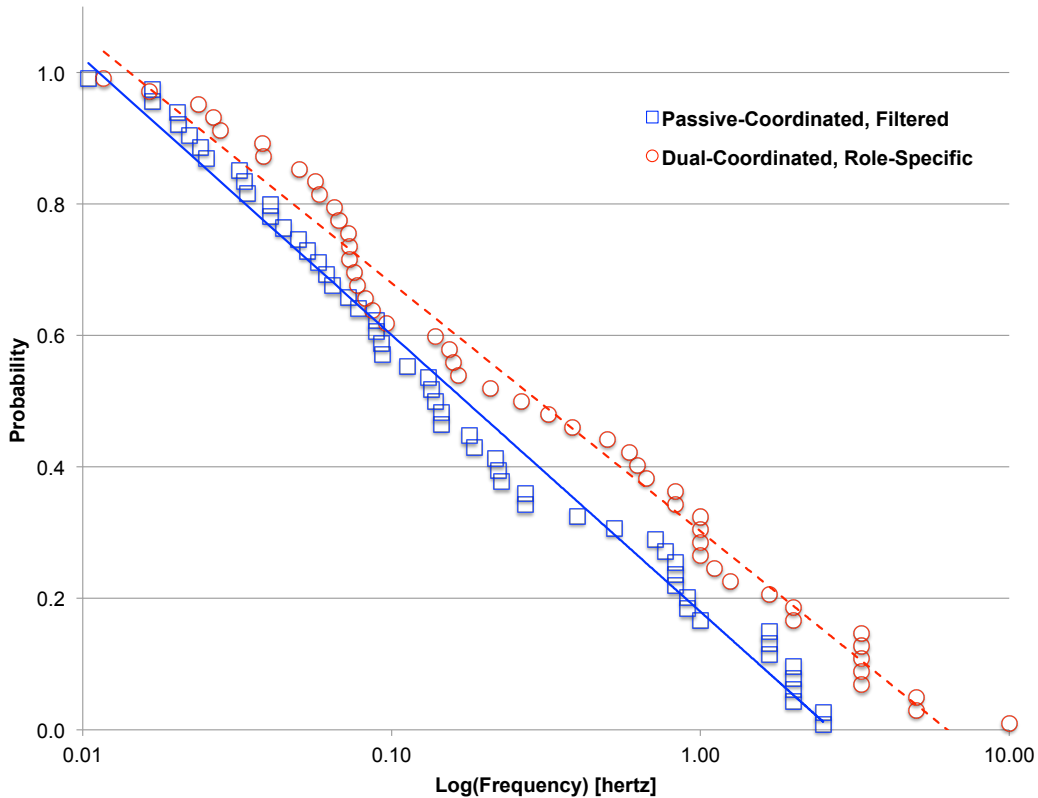


Fig. 7.2. Empirical Cumulative Distribution Functions for Object Identification Task Completion Frequency by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Frequency Measurements ($n = 57$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Frequency Series. Red Circles Represent Dual-Coordinated, Role-Specific Frequency Measurements ($n = 51$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Frequency Series. The Frequency Measurements are Displayed on a Logarithmic Scale.

Table 7.2
Results of Statistical Difference of Means and Medians Tests Between
Interface Conditions for Object Identification Task Completion Time.

Statistical Parameter ¹	Passive-Coordinated, Filtered	Dual-Coordinated, Role-Specific	Significance (<i>p</i> -value)
Geometric Mean ²	5.8	3.3	0.096
Median	7.2	3.8	0.117

¹ Each statistical parameter is reported in units of seconds.

² Geometric mean is reported as per [64]; refer to Table 7.1 for the complete set of descriptive statistics.

For the passive-coordinated, filtered eCDF, the Lilliefors test ($KS = 0.11$, $cv_L = 0.12$, $p = 0.067$), Jarque-Bera test ($JB = 3.58$, $cv_{JB} = 5.08$, $p = 0.088$), and normal quantile plot correlation ($r_{qp} = 0.980$) showed that the log transformed time data follow a normal distribution. In the case of the the dual-coordinated, role-specific eCDF, the Lilliefors test ($KS = 0.13$, $cv_L = 0.12$, $p = 0.027$), Jarque-Bera test ($JB = 2.84$, $cv_{JB} = 4.99$, $p = 0.122$), and normal quantile plot correlation ($r_{qp} = 0.984$) suggested that the log transformed time data follow a normal distribution. Results of the equivalence of variances *F*-test determined the log transformed passive-coordinated, filtered and dual-coordinated, role-specific eCDF time series have equivalent variances ($F = 0.80$, $df_n = 56$, $df_d = 50$, $p = 0.424$).

Results for object identification task completion time eCDF equivalence of means and medians are summarized in Table 7.2. Welch's *t*-test determined there was not a statistically significant difference between the means of the passive-coordinated, filtered and dual-coordinated, role-specific interfaces ($t = 1.68$, $df = 101$, $p = 0.096$). The Wilcoxon rank sum test determined there was not a statistically significant difference between the medians of the two interface conditions ($p = 0.117$). The statistical test results for equivalence of means and medians showed that a *Mission Specialist* completed object identifica-

tion tasks in the same amount of time using both interfaces; therefore, research hypothesis 1 was supported (Section 6.2.1)

7.1.2 Evaluation Tasks

The descriptive and inferential statistical results for evaluation task completion time by interface condition are given in this section. Results were found not to be statistically significantly different between the two interface conditions; therefore, a *Mission Specialist* using either the passive-coordinated, filtered or the dual-coordinated, role-specific interface completed evaluation tasks in a similar amount of time. Evaluation task completion time data for both interface conditions were shown to follow a log-normal distribution with equal variances.

7.1.2.1 Descriptive Statistical Analyses for Evaluation Task Completion Time

Descriptive statistics for evaluation task completion time are shown in Table 7.3. Evaluation task completion when using the dual-coordinated, role-specific interface condition was determined to be arithmetically faster ($AM = 10.2$ -seconds, $SD = 12.0$ -seconds) than evaluation task completion when using the passive-coordinated, filtered interface condition ($AM = 13.4$ -seconds, $SD = 23.8$ -seconds). The dual-coordinated, role-specific interface condition was geometrically faster ($GM = 4.8$ -seconds, $GSD = 4.3$ -seconds) than the passive-coordinated, filtered interface condition ($GM = 6.7$ -seconds, $GSD = 3.1$ -seconds). The median evaluation completion time was faster for the dual-coordinated, role-specific condition ($M = 6.5$ -seconds) versus the passive-coordinated, filtered condition ($M = 6.7$ -seconds). The dual-coordinated, role-specific interface condition had positive skewness ($s = 2.1$) and was leptokurtic ($k = 7.5$); the passive-coordinated, filtered interface condition had similar results ($s = 4.7$, $k = 27.7$). Considering geometric mean as the primary measure for evaluation task completion, evaluating objects and information when using the

Table 7.3
Descriptive Statistical Results for Evaluation Task Completion Time Between Interface Conditions.

Descriptive Statistic¹	Passive-Coordinated, Filtered	Dual-Coordinated, Role-Specific
Arithmetic Mean (<i>AM</i>)	13.4	10.2
Standard Deviation (<i>SD</i>)	23.8	12.0
Geometric Mean (<i>GM</i>)	6.7	4.8
Geometric Standard Deviation (<i>GSD</i>)	3.1	4.3
Median (<i>M</i>)	6.7	6.5
Skewness (<i>s</i>)	4.7	2.1
Kurtosis (<i>k</i>)	27.7	7.5

¹ Each descriptive statistic is reported in units of seconds except for skewness and kurtosis which are dimensionless quantities.

dual-coordinated, role-specific interface was accomplished, on average, 1.9-seconds (or 1.4 times) faster than when using the passive-coordinated, filtered interface.

7.1.2.2 Inferential Statistical Analyses for Evaluation Task Completion Time

Evaluation task completion time-based eCDFs were developed for each interface condition (Figure 7.3). A line of best fit was determined for each evaluation task completion eCDF time series. For the passive-coordinated, filtered and dual-coordinated, role-specific time-based eCDFs, the determined lines of best fit are given by Equation 7.3 ($R^2 = 0.938$) and Equation 7.4 ($R^2 = 0.913$), respectively:

$$P = 0.249 \ln(t) + 0.025 \quad (7.3)$$

$$P = 0.189 \ln(t) + 0.206 \quad (7.4)$$

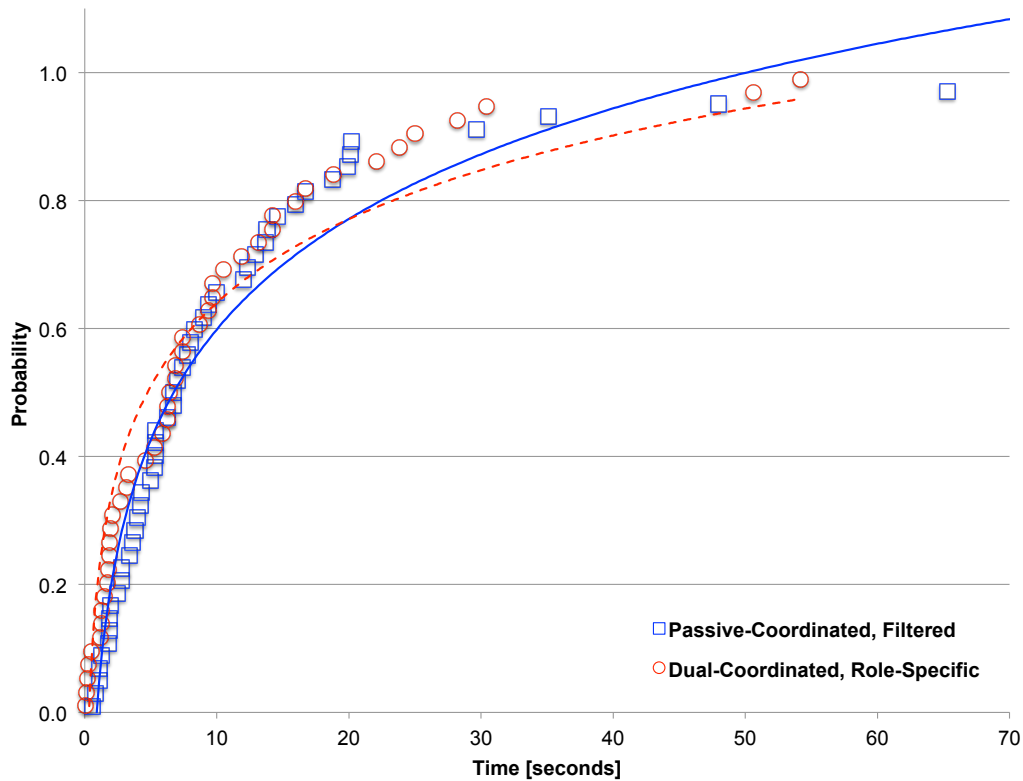


Fig. 7.3. Empirical Cumulative Distribution Functions for Evaluation Task Completion Time by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Time Measurements ($n = 51$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Time Series. Red Circles Represent Dual-Coordinated, Role-Specific Time Measurements ($n = 47$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Time Series.

where P is the eCDF probability and t is evaluation task completion time in seconds. A frequency-based representation for each evaluation task completion eCDF is shown in Figure 7.4 to provide an alternative view of evaluation task completion speed. As can be observed in Figure 7.4, the dual-coordinated, role-specific interface appears to result in faster evaluation task completion.

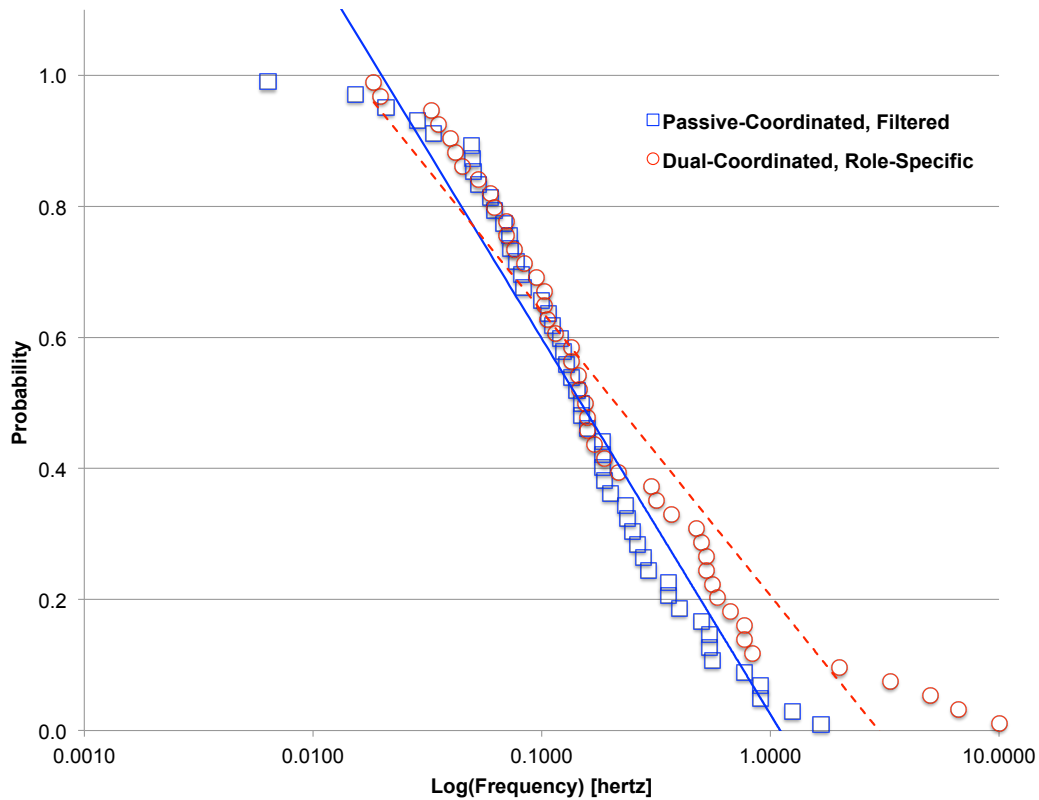


Fig. 7.4. Empirical Cumulative Distribution Functions for Evaluation Task Completion Frequency by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Frequency Measurements ($n = 51$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Frequency Series. Red Circles Represent Dual-Coordinated, Role-Specific Frequency Measurements ($n = 47$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Frequency Series. The Frequency Measurements are Displayed on a Logarithmic Scale.

Table 7.4
Results of Statistical Difference of Means and Medians Tests Between
Interface Conditions for Evaluation Task Completion Time.

Statistical Parameter ¹	Passive-Coordinated, Filtered	Dual-Coordinated, Role-Specific	Significance (<i>p</i> -value)
Geometric Mean ²	5.8	3.3	0.197
Median	7.2	3.8	0.493

¹ Each statistical parameter is reported in units of seconds.

² Geometric mean is reported as per [64]; refer to Table 7.3 for the complete set of descriptive statistics.

A visual inspection of Figures 7.3 and 7.4 and the determination of the lines of best fit suggested the evaluation task completion time eCDF data follow a log-normal distribution; therefore, the time series data were log transformed and tested for normality. For the passive-coordinated, filtered eCDF, the Lilliefors test ($KS = 0.07$, $cv_L = 0.12$, $p = 0.500$), Jarque-Bera test ($JB = 0.43$, $cv_{JB} = 4.99$, $p = 0.500$), and normal quantile plot correlation ($r_{qp} = 0.993$) showed that the log transformed time data follow a normal distribution. In the case of the the dual-coordinated, role-specific eCDF, the Lilliefors test ($KS = 0.13$, $cv_L = 0.13$, $p = 0.038$), Jarque-Bera test ($JB = 4.63$, $cv_{JB} = 4.91$, $p = 0.055$), and normal quantile plot correlation ($r_{qp} = 0.984$) suggested that the log transformed time data follow a normal distribution. Results of the equivalence of variances *F*-test determined the log transformed passive-coordinated, filtered and dual-coordinated, role-specific eCDF time series have equivalent variances ($F = 0.59$, $df_n = 50$, $df_d = 46$, $p = 0.068$).

Results for evaluation task completion time eCDF equivalence of means and medians are summarized in Table 7.4. Welch's *t*-test determined there was not a statistically significant difference between the means of the passive-coordinated, filtered and dual-coordinated, role-specific interfaces ($t = 1.30$, $df = 86$, $p = 0.197$). The Wilcoxon rank sum test determined there was not a statistically significant difference between the medians of the two interface conditions ($p = 0.493$). The statistical test results for equivalence

of means and medians showed that a *Mission Specialist* completed evaluation tasks in the same amount of time using both interfaces; therefore, research hypothesis 1 was supported (Section 6.2.1)

7.1.3 Image Capture Tasks

The descriptive and inferential statistical results for image capture task completion time by interface condition are given in this section. Results were found not to be statistically significantly different between the two interface conditions; therefore, a *Mission Specialist* using either the passive-coordinated, filtered or the dual-coordinated, role-specific interface completed image capture tasks in a similar amount of time. Image capture task completion time data for both interface conditions were shown to follow a log-normal distribution with equal variances.

7.1.3.1 Descriptive Statistical Analyses for Image Capture Task Completion Time

Descriptive statistics for image capture task completion time are shown in Table 7.5. Image capture task completion when using the passive-coordinated, filtered interface condition was determined to be arithmetically faster ($AM = 17.3$ -seconds, $SD = 27.4$ -seconds) than image capture task completion when using the dual-coordinated, role-specific interface condition ($AM = 21.9$ -seconds, $SD = 34.5$ -seconds). The dual-coordinated, role-specific interface condition was geometrically faster ($GM = 5.6$ -seconds, $GSD = 6.4$ -seconds) than the passive-coordinated, filtered interface condition ($GM = 6.7$ -seconds, $GSD = 4.1$ -seconds). The median image capture completion time was faster for the dual-coordinated, role-specific condition ($M = 6.9$ -seconds) versus the passive-coordinated, filtered condition ($M = 7.0$ -seconds). The dual-coordinated, role-specific interface condition had positive skewness ($s = 2.0$) and was leptokurtic ($k = 6.2$); the passive-coordinated, filtered interface condition had similar results ($s = 2.6$, $k = 9.5$). Considering geometric mean as the primary measure for image capture task completion, capturing images of objects and

Table 7.5
Descriptive Statistical Results for Image Capture Task Completion Time
Between Interface Conditions.

Descriptive Statistic ¹	Passive-Coordinated, Filtered	Dual-Coordinated, Role-Specific
Arithmetic Mean (<i>AM</i>)	17.3	21.9
Standard Deviation (<i>SD</i>)	27.4	34.5
Geometric Mean (<i>GM</i>)	6.7	5.6
Geometric Standard Deviation (<i>GSD</i>)	4.1	6.4
Median (<i>M</i>)	7.0	6.9
Skewness (<i>s</i>)	2.6	2.0
Kurtosis (<i>k</i>)	9.5	6.2

¹ Each descriptive statistic is reported in units of seconds except for skewness and kurtosis which are dimensionless quantities.

information when using the dual-coordinated, role-specific interface was accomplished, on average, 1.1-seconds (or 1.2 times) faster than when using the passive-coordinated, filtered interface.

7.1.3.2 Inferential Statistical Analyses for Image Capture Task Completion Time

Image capture task completion time-based eCDFs were developed for each interface condition (Figure 7.5). A line of best fit was determined for each image capture task completion eCDF time series. For the passive-coordinated, filtered and dual-coordinated, role-specific time-based eCDFs, the determined lines of best fit are given by Equation 7.5 ($R^2 = 0.981$) and Equation 7.6 ($R^2 = 0.978$), respectively:

$$P = 0.204 \ln(t) + 0.113 \quad (7.5)$$

$$P = 0.154 \ln(t) + 0.231 \quad (7.6)$$

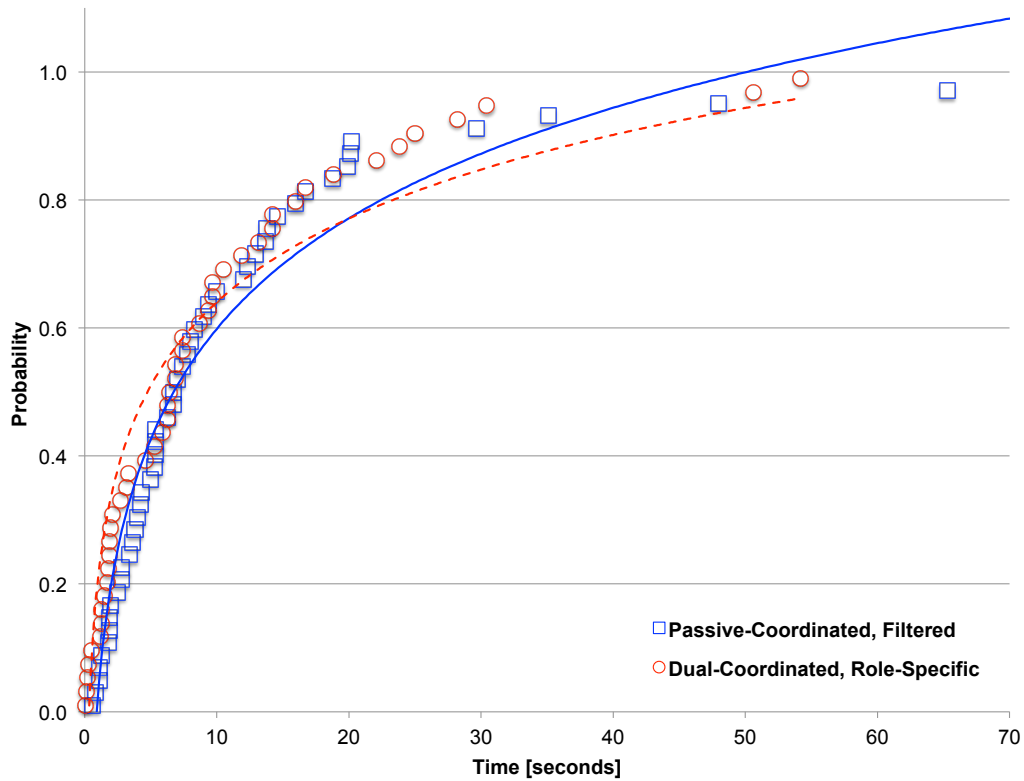


Fig. 7.5. Empirical Cumulative Distribution Functions for Image Capture Task Completion Time by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Time Measurements ($n = 49$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Time Series. Red Circles Represent Dual-Coordinated, Role-Specific Time Measurements ($n = 46$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Time Series.

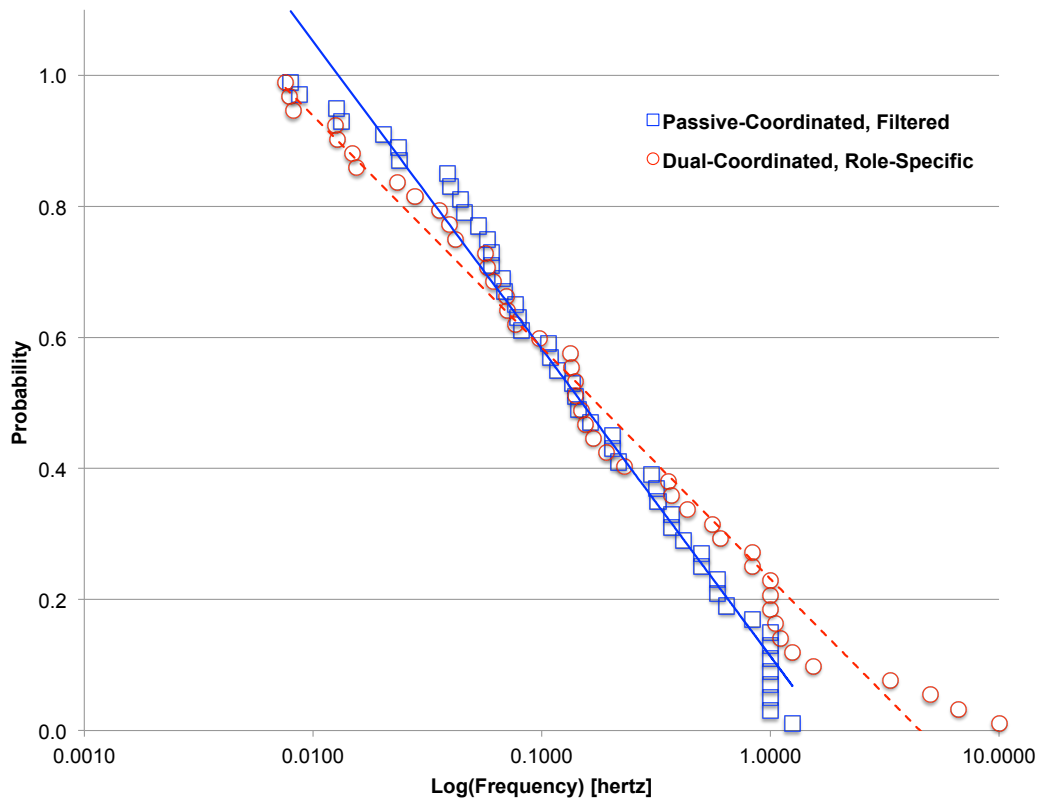


Fig. 7.6. Empirical Cumulative Distribution Functions for Image Capture Task Completion Frequency by Interface Condition. Blue Squares Represent Passive-Coordinated, Filtered Frequency Measurements ($n = 49$). The Solid Blue Line is the Line of Best Fit for the Passive-Coordinated, Filtered Frequency Series. Red Circles Represent Dual-Coordinated, Role-Specific Frequency Measurements ($n = 46$). The Dashed Red Line is the Line of Best Fit for the Dual-Coordinated, Role-Specific Frequency Series. The Frequency Measurements are Displayed on a Logarithmic Scale.

where P is the eCDF probability and t is image capture task completion time in seconds. A frequency-based representation for each image capture task completion eCDF is shown in Figure 7.6 to provide an alternative view of image capture task completion speed. As can be observed in Figure 7.6, the dual-coordinated, role-specific interface appears to result in faster image capture task completion.

A visual inspection of Figures 7.5 and 7.6 and the determination of the lines of best fit suggested the image capture task completion time eCDF data follow a log-normal distribution; therefore, the time series data were log transformed and tested for normality. For the passive-coordinated, filtered eCDF, the Lilliefors test ($KS = 0.09$, $cv_L = 0.13$, $p = 0.403$), Jarque-Bera test ($JB = 2.15$, $cv_{JB} = 4.95$, $p = 0.195$), and normal quantile plot correlation ($r_{qp} = 0.984$) showed that the log transformed time data follow a normal distribution. In the case of the the dual-coordinated, role-specific eCDF, the Lilliefors test ($KS = 0.08$, $cv_L = 0.13$, $p = 0.500$), Jarque-Bera test ($JB = 1.29$, $cv_{JB} = 4.89$, $p = 0.392$), and normal quantile plot correlation ($r_{qp} = 0.992$) showed that the log transformed time data follow a normal distribution. Results of the equivalence of variances F -test determined the log transformed passive-coordinated, filtered and dual-coordinated, role-specific eCDF time series do not have equivalent variances ($F = 0.53$, $df_n = 48$, $df_d = 45$, $p = 0.033$).

Results for image capture task completion time eCDF equivalence of means and medians are summarized in Table 7.6. Welch's t -test determined there was not a statistically significant difference between the means of the passive-coordinated, filtered and dual-coordinated, role-specific interfaces ($t = 0.26$, $df = 82$, $p = 0.794$). The Wilcoxon rank sum test determined there was not a statistically significant difference between the medians of the two interface conditions ($p = 0.882$). The statistical test results for equivalence of means and medians showed that a *Mission Specialist* completed image capture tasks in the same amount of time using both interfaces; therefore, research hypothesis 1 was supported (Section 6.2.1)

Table 7.6
Results of Statistical Difference of Means and Medians Tests Between
Interface Conditions for Image Capture Task Completion Time.

Statistical Parameter¹	Passive-Coordinated, Filtered	Dual-Coordinated, Role-Specific	Significance (<i>p</i>-value)
Geometric Mean ²	6.7	5.6	0.794
Median	7.0	6.9	0.882

¹ Each statistical parameter is reported in units of seconds.

² Geometric mean is reported as per [64]; refer to Table 7.5 for the complete set of descriptive statistics.

7.2 Levels of Stress Analyses and Results

This section presents the data analyses performed for heart rate data as a measure of levels of stress for the two different interface conditions (passive-coordinated, filtered versus dual-coordinated, role-specific). Descriptive and inferential statistical results are provided for the heart rate data.

Descriptive statistical analyses for the heart rate data were completed using the accompanying Biopack® BioNomadix software and MATLAB®. The descriptive statistical analyses consisted of calculating the arithmetic mean (*AM*) for each heart rate time series recorded for each interface condition.

Inferential statistical analyses were performed using MATLAB® for the heart rate data interface condition. Repeated measures analyses were performed for the within-subjects factor of interface condition (passive-coordinated, filtered versus dual-coordinated, role-specific). The dependent variable in each analysis was arithmetic mean heart rate in beats per minute, which was evaluated for statistical significance through a two-way analysis of variance (ANOVA). Statistical results are reported by an *F*-statistic with accompanying degrees of freedom (*df*), and statistical significance (*p*-value).

7.2.1 Heart Rate Descriptive Statistical Analyses

Descriptive statistics for participant heart rate in each interface condition (passive-coordinated, filtered and dual-coordinated, role-specific) are shown in Table 7.7. Three participants experienced a slower average heart rate when using the dual-coordinated, role-specific interface than when using the passive-coordinated, filtered interface; six participants experience a faster average heart rate. One participant experienced no difference in heart rate between interface conditions.

Table 7.7
Arithmetic Mean Results for Participant Heart Rate Between Interface Conditions.

Participant	Passive-Coordinated, Filtered¹	Dual-Coordinated, Role-Specific¹
1	86	80
2	75	79
3	88	88
4	88	89
5	83	88
6	76	80
7	77	84
8	73	67
9	71	75
10	76	75

¹ Arithmetic mean values are reported in beats per minute.

7.2.2 Heart Rate Inferential Statistical Analyses

Results for the two-way ANOVA test determined there was not a statistically significant difference between the mean heart rate measured for participants when using the passive-coordinated, filtered and dual-coordinated, role-specific interfaces ($F = 0.16$, $df = 1$, $p = 0.693$). The statistical test results showed that a *Mission Specialist* experienced the same level of stress as measured by heart rate using both interfaces; therefore, research hypothesis 2 was supported (Section 6.2.2)

7.3 Role Empowerment Analyses and Results

This section presents the data analyses performed for the summative post-assessment data reported for participant role empowerment (confidence, comfort, and perceived best individual and team performance) when considering both interface conditions (passive-

Table 7.8
Descriptive Statistical Results for Reported Role Empowerment Confidence Between Interface Conditions.

Participant Activity	Passive-Coordinated, Filtered¹	Dual-Coordinated, Role-Specific¹
Locate Objects (Individual)	10	90
Capture Images (Individual)	10	90
Capture Images (Team)	40	60
Camera Tilt (Individual)	50	50
Camera Zoom (Individual)	50	50

¹ Values reported are percentage of participants indicating the interface condition gave them the most confidence for the specified activity.

coordinated, filtered and dual-coordinated, role-specific). Descriptive statistical analyses were performed for the role empowerment data using MATLAB®. Since the reported role empowerment data were categorical, the descriptive statistical analyses consisted of percentages of total participants for each post-assessment survey question type (e.g., which method gave the most confidence for capturing images). The determined percentages for confidence and comfort are provided in Tables 7.8 and 7.9, respectively.

7.3.1 Locating Objects

Ninety percent (90%) of all participants reported the most individual confidence in the dual-coordinated, role-specific interface for locating objects. Ten percent (10%) indicated the most individual confidence came from using the passive-coordinated, filtered interface. Sixty percent (60%) of all participants reported the most individual comfort using the dual-coordinated, role-specific interface to locate objects. Forty percent (40%) of participants reported that using the passive-coordinated, filtered interface and asking the *Pilot* was more comfortable for them individually. Therefore, the dual-coordinated, role-specific interface provided greater role empowerment (confidence and comfort) for a

Table 7.9
Descriptive Statistical Results for Reported Role Empowerment Comfort
Between Interface Conditions.

Participant Activity	Passive-Coordinated, Filtered¹	Dual-Coordinated, Role-Specific¹
Locate Objects (Individual)	40	60
Capture Images (Individual)	20	80
Capture Images (Team)	30	60
Camera Tilt (Individual)	50	50
Camera Zoom (Individual)	50	50

¹ Values reported are percentage of participants indicating the interface condition was the most comfortable for them for the specified activity.

Mission Specialist to individually locate objects and research hypothesis 3 was supported (Section 6.2.3)

7.3.2 Capturing Images

Ninety percent (90%) of all participants reported the most individual confidence in the dual-coordinated, role-specific interface for capturing images. Ten percent (10%) indicated the most individual confidence came from using the passive-coordinated, filtered interface. Eighty percent (80%) of all participants reported the most individual comfort using the dual-coordinated, role-specific interface to capture images. Twenty percent (20%) of participants reported that using the passive-coordinated, filtered interface and asking the *Pilot* was more comfortable for them individually.

Sixty percent (60%) of participants reported the most confidence when using the dual-coordinated, role-specific interface for their team's ability capturing images. Forty percent (40%) indicated the most confidence in their team came from using the passive-coordinated, filtered interface. Sixty percent (60%) of all participants reported the most comfort for their team using the dual-coordinated, role-specific interface to capture images. Forty percent (40%) of participants reported that using the passive-coordinated, filtered interface and asking the *Pilot* was more comfortable for them in the context of the team.

The dual-coordinated, role-specific interface provided greater role empowerment (confidence and comfort) for a *Mission Specialist* to individually and, as a team, capture images; thus, research hypothesis 3 was supported (Section 6.2.3)

7.3.3 Payload Camera Tilt

Fifty percent (50%) of all participants reported the most individual confidence in the dual-coordinated, role-specific interface for tilting the payload camera. Fifty percent (50%) indicated the most individual confidence came from using the passive-coordinated,

filtered interface. Fifty percent (50%) of all participants reported the most individual comfort using the dual-coordinated, role-specific interface to tilt the payload camera. Fifty percent (50%) of participants reported that using the passive-coordinated, filtered interface and asking the *Pilot* was more comfortable for them individually. Therefore, the dual-coordinated, role-specific interface provided the same role empowerment (confidence and comfort) for a *Mission Specialist* to individually tilt the payload camera and research hypothesis 3 was supported (Section 6.2.3)

7.3.4 Payload Camera Zoom

Fifty percent (50%) of all participants reported the most individual confidence in the dual-coordinated, role-specific interface for zooming the payload camera. Fifty percent (50%) indicated the most individual confidence came from using the passive-coordinated, filtered interface. Fifty percent (50%) of all participants reported the most individual comfort using the dual-coordinated, role-specific interface to zoom the payload camera. Fifty percent (50%) of participants reported that using the passive-coordinated, filtered interface and asking the *Pilot* was more comfortable for them individually. Therefore, the dual-coordinated, role-specific interface provided the same role empowerment (confidence and comfort) for a *Mission Specialist* to individually zoom the payload camera and research hypothesis 3 was supported (Section 6.2.3)

7.3.5 Perceived Best Individual and Team Performance

Participants responded to one question asking which interface method provided them with the best individual performance for acquiring images of identified objects. Three possible answer responses were given for both questions and included i) controlling the payload camera themselves, ii) only asking the *Pilot* to control the payload camera, or iii) both doing it themselves and asking the *Pilot*. The determined percentages for perceived best individual and team performance are provided in Table 7.10.

Table 7.10

Descriptive Statistical Results for Reported Best Individual and Team Performance Between Interface Conditions.

Participant Perception	Passive-Coordinated, Filtered¹	Dual-Coordinated, Role-Specific¹
Best Individual Performance	40	60
Best Team Performance	40	60

¹ Values reported are percentage of participants indicating the interface condition gave them or their team the best performance.

Sixty percent (60%) of all participants reported that their best individual performance for acquiring images of objects resulted from the interface method where they had both active control of the payload camera and were able to verbally coordinate with the *Pilot* (dual-coordinated, role-specific). Forty percent (40%) of participants reported that their best individual performance for acquiring images of objects resulted from the interface where they passively viewed the mirrored display and only verbally coordinated with the *Pilot* (passive-coordinated, filtered).

Sixty percent (60%) of all participants reported that the performance from their team for acquiring images of objects resulted from the interface method where they had both active control of the payload camera and were able to verbally coordinate with the *Pilot* (dual-coordinated, role-specific). Forty percent (40%) of participants reported that the performance from their team for acquiring images of objects resulted from the interface where they passively viewed the mirrored display and only verbally coordinated with the *Pilot* (passive-coordinated, filtered).

The dual-coordinated, role-specific interface provided greater role empowerment (perceived best individual and team performance) for a *Mission Specialist* to locate objects and capture images; thus, research hypothesis 3 was supported (Section 6.2.3).

7.4 Summary

This section presented the statistical analyses and results for data collected as part of an experimental field study and determined the appropriate human-robot interface for a *Mission Specialist* in a micro UAS is a role-specific visual common ground interface permitting shared control of the payload camera and verbal coordination with the *Pilot*.

Analyses of task completion time in three separate task categories (object identification, evaluation, and image capture) showed that a *Mission Specialist* using a dual-coordinated, role-specific interface completed tasks in the same amount of time as when using a passive-coordinated, filtered interface. These results supported research hypothesis 1 (Section 6.2.3).

An analyses of participant heart rate data determined that a *Mission Specialist* will experience the same level of stress regardless of the interface condition they use (dual-coordinated, role-specific or passive-coordinated, filtered). The results of the levels of stress analyses supported research hypothesis 2 (Section 6.2.2).

Role empowerment (confidence, comfort, and perceived best individual and team performance) analyses showed that a *Mission Specialist* preferred a dual-coordinated, role-specific interface over a passive-coordinated, filtered interface. These results supported research hypothesis 3 (Section 6.2.3).

8. DISCUSSION

This section discusses and interprets the results obtained from the experimental field study, describes three trends observed from the collected data, and identifies two factors that may have impacted the result outcomes. The results from this dissertation research revealed three interesting trends associated with *Mission Specialist* interfaces in a micro UAS: i) command-level experience affects control preference, ii) perceived responsibility for the robot affects control preference, and iii) level of control and focused visual common ground form a space of interaction for the Shared Roles Model. The micro category of UAS is the most accessible technology for civilian-supported CBRN operations such as fire and rescue, law enforcement, and civil engineering and legislative trends suggest that micro UAS are in high demand for these domains and will become widely available to *ad hoc* users much faster than any other category of UAS. Understanding how these different types of users will perform in the *Mission Specialist* role is essential for mUAS mission planning and success.

8.1 Task Completion Time Discussion

Each of the three task categories a *Mission Specialist* completed (object identification, evaluation, image capture) were determined to take the same amount of time, if the *Mission Specialist* had shared control of the payload camera versus was only able to instruct the *Pilot* for payload camera control. The numeric results shown in Tables 7.1, 7.3, and 7.5 suggest that on average, a *Mission Specialist* can complete tasks faster with the dual-coordinated, role-specific interface, though with large variation which would likely depend on the type of task being attempted.

8.1.1 Object Identification Tasks

The most significantly different task completion time category was object identification as it showed, on average, the greatest difference when the *Mission Specialist* used the dual-coordinated, role-specific interface. Object identification tasks were the initial tasks asked of each participant when they arrived at a waypoint. The improvement in task completion time was likely due to the *Mission Specialist* having direct control of the payload camera and being able to more quickly search for an object with their own interface versus issuing verbal instructions for individual payload camera movements. This would assist specialized responders as faster object identification would aid decision making.

8.1.2 Evaluation Tasks

Evaluation tasks were completed approximately 1.4 times faster when a *Mission Specialist* used the dual-coordinated, role-specific interface. Evaluation tasks were the secondary tasks asked of each participant once they identified an object (e.g., getting a specific number from a derailed train car). Improvement in this task completion category suggests that a *Mission Specialist* would be able to obtain critical information regarding an identified object of interest faster than if they were only viewing a mirrored interface and instructing the *Pilot*. Specialized responders often gain a deeper understanding for operational planning with this type of information (e.g., determining the type of chemical present in a derailment).

8.1.3 Image Capture Tasks

The most similar task completion time result between the two interface conditions was for capturing images. All participants when using the dual-coordinated, role-specific interface were observed trying to properly frame the object of interest in the center of the screen prior to capturing an image, likely leading to a longer task completion times. When

participants directed the *Pilot* to capture an image, a focus on framing was not observed; the task was essentially out of the participants' control. A greater focus by participants on capturing the image themselves could correlate with the high internal locus of control observed in all of the participants. Further study would be warranted to determine the exact cause of the observed extended time spent properly framing images.

8.2 Levels of Stress Discussion

A *Mission Specialist* when using the dual-coordinated, role-specific interface did not experience any more stress than when using the passive-coordinate, filtered interface. Each of the participants had been trained as a specialized emergency responder to work in high-stress situations (e.g., HAZMAT, search and rescue, etc.); therefore, as realistic as the simulated train derailment was, it may not have fully replicated the conditions for which they are uniquely trained. Additionally, both types of interfaces used in the experimental field study conditions represented a new experience to each of the participants; thus, a non-statistically significant level of stress recorded may have reflected the general lack of familiarity with both of the interface technologies. Alternatively, this may be a very positive finding, in general, if neither interface condition causes stressful conditions; more work to evaluate levels of stress in specialized responders when using different types of robotics-based technologies should be undertaken.

8.3 Role Empowerment Discussion

The most significant experimental finding was that greater role empowerment was experienced by a *Mission Specialist* when using a dual-coordinated, role-specific interface. As was shown in Table 7.8, the most significant result observed was a *Mission Specialist* preferring the choice to either capture images themselves or instruct the *Pilot* to capture images. Each subsequent role empowerment category related to payload camera control and perceived best individual and team performance also showed a majority or balanced

preference. Results in the subsequent role empowerment categories are likely less strong due to contention observed between the *Mission Specialist* and *Pilot* for control of the payload camera. All participants, when given the choice, used both direct control and verbal coordination with the *Pilot* for payload camera control and capturing images. However, there was also at least once instance where each participant asked the *Pilot* to control the payload camera (e.g., tilt down) while simultaneously attempting to issue the same command themselves through the interface. This contention caused movement of the payload camera beyond what was initially desired by the *Mission Specialist* and had to be corrected with additional inputs.

8.4 Formative Observations

Command experience and perceived responsibility for the robot were observed to affect *Mission Specialist* interface preference. *Mission Specialist* participants with command-level experience preferred shared control while non-commanders preferred only to ask the *Pilot* for control of the payload camera. Participants who reported they would be responsible for the robot's maintenance and upkeep did not want shared control and instead preferred to only communicate with the *Pilot*. These formative observations suggest that work experience and responsibility for the robot by the *Mission Specialist* influence the preferred method of HRI for micro UAS operations.

8.4.1 The Commander Effect

A *Mission Specialist* having command-level experience (e.g., Fire and Rescue Captain, EMS Team Leader) reported the greatest role empowerment using the dual-coordinated, role-specific interface. Conversely, a *Mission Specialist* with non-command-level experience (e.g., HAZMAT technician, search and rescue team member) reported the greatest role empowerment resulted from only instructing the *Pilot* for payload camera control and image capture. This *Commander Effect* was determined through a correlation analysis

Table 8.1
Correlation Findings Between Level of Command Experience and Reported Role Empowerment.

Role Empowerment Category	Correlation Coefficient
Best Performance (Team)	1.00
Capturing Images	1.00
Best Performance (Individual)	0.82
Locating Objects	0.80
Zooming the Payload Camera	0.80

between command-level experience reported through the pre-assessment survey and each role empowerment category reported through the summative post-assessment survey. Each role empowerment category, except confidence and comfort for payload camera tilt, was determined to correlate at a statistically significant level ($p < 0.05$) with command-level experience (Table 8.1).

8.4.2 The Responsibility Effect

Mission Specialist participants who reported they would be responsible for maintenance of the robot reported their perceived best individual performance came from using the passive-coordinated, filtered interface. Conversely, a *Mission Specialist* who reported they would not be responsible for maintenance for the robot reported their perceived best individual performance resulted from shared control of the payload camera with the *Pilot*. This *Responsibility Effect* was determined through a correlation analysis between indicated responsibility and each role empowerment category reported through the summative post-assessment survey. Perceived best individual performance and, interestingly, confi-

Table 8.2
Correlation Findings Between Reported Responsibility for the Robot and Reported Role Empowerment.

Role Empowerment Category	Correlation Coefficient
Best Performance (Individual)	0.60
Tilting the Payload Camera	0.60

dence and comfort in payload camera tilt, were determined to correlate at a statistically significant level ($p < 0.05$) with responsibility for the robot (Table 8.2). Confidence and comfort in payload camera tilt were interesting because it was the only role empowerment category that did not correlate with the observed *Commander Effect* (the explanation for this is that one third of commanders preferred to ask the *Pilot* to tilt the payload camera). There was no correlation found between the *Commander Effect* and the *Responsibility Effect*.

8.5 Dimensions of the Shared Roles Model

A significant finding of this research was that the Shared Roles Model formulation for micro UAS has two dimensions (*Mission Specialist* control and focused visual common ground) that form a space of nine interaction states (Figure 8.1). Using these nine interaction states, results from the exploratory and experimental field studies combined with the two formative observations (the *Commander Effect* and the *Responsibility Effect*) revealed conclusively that the dual-coordinated, role-specific interface is the most appropriate interface for a *Mission Specialist* to use for increasing individual performance.

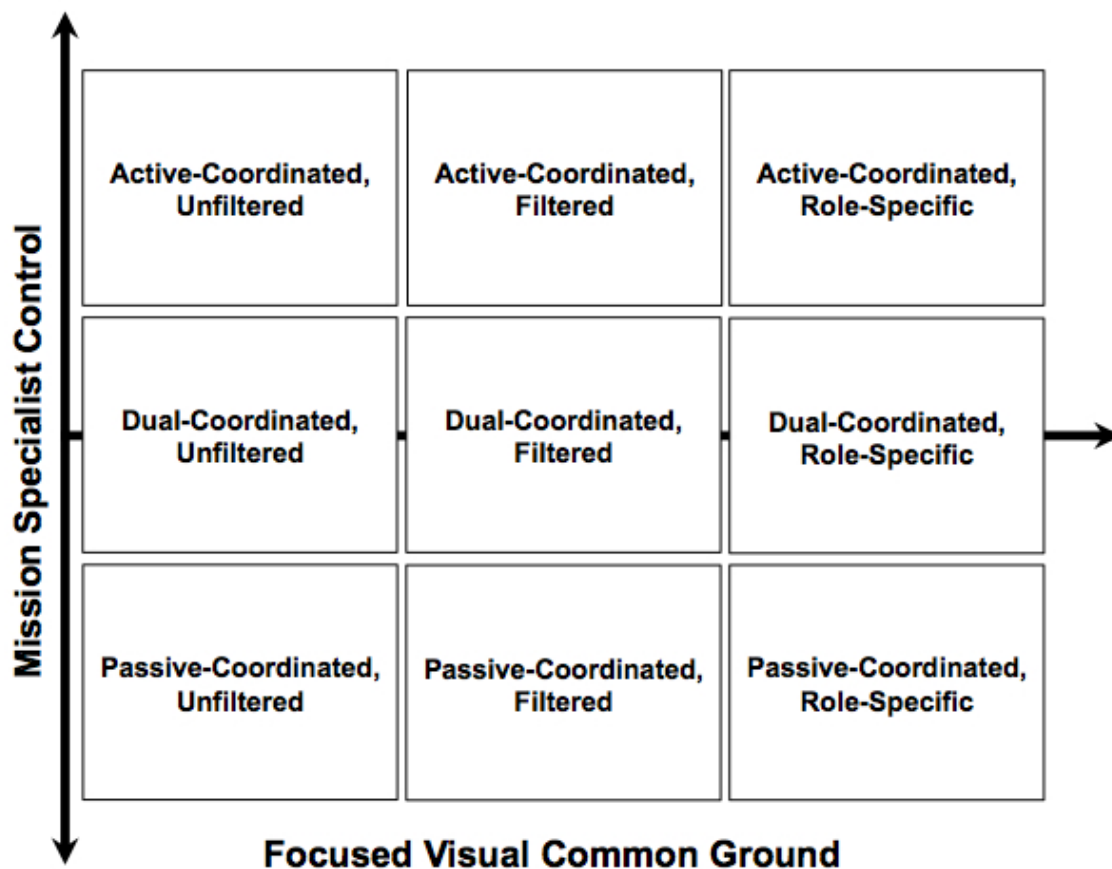


Fig. 8.1. Nine States of the Shared Roles Model Across Two Dimensions - Focused Visual Common Ground and *Mission Specialist* Control. The Rows Represent Level of Control from Passive (None), to Dual (Shared), to Active (Full). The Columns Represent Common Ground Focus of the Interface from Unfiltered (None), to Filtered (*Pilot-Only* Artifacts Removed), to Role-Specific (Additional *Mission Specialist-Only* Information Added).

8.5.1 *Mission Specialist Control*

The exploratory field study evaluated the passive-coordinated, filtered and the active-coordinated, filtered interfaces. In this set of interface conditions, either the *Pilot* controlled the payload camera based on instructions from the *Mission Specialist*, or the *Mission Specialist* controlled the payload camera themselves, respectively; there was no shared control. The results showed that a *Mission Specialist* preferred the passive-coordinated, filtered interface condition and did not want active (sole) control of the payload camera. This result indicated that an upper bound on *Mission Specialist* control can be placed for active-coordination for any of the three states in which active control is present.

8.5.2 *Focused Visual Common Ground*

Another important finding of the exploratory field study was a lack of adequate visual feedback and the need for more role focused information (i.e., focused visual common ground). The experimental field study evaluated the passive-coordinated, filtered and the dual-coordinated, role-specific interfaces. The results showed that a *Mission Specialist* preferred the interface with shared control of the payload camera and verbal coordination with the *Pilot* (i.e., dual-coordinated, role-specific). This result indicated that a lower bound on focused visual common ground can be placed at the filtered level as role-specific information was clearly preferred. For the remaining two states of the Shared Roles Model, dual-coordinated, role-specific and passive-coordinated, role-specific, the *Commander Effect* and the *Responsibility Effect* show that the dual-coordinated, role-specific interface is most appropriate. This is conclusive because the dual-coordinated, role-specific interface accommodates both effects; non-commanders and those who would be responsible for the robot can use the dual-coordinated, role-specific interface as passive viewers, but the reverse is not true.

8.6 Factors that May Have Impacted the Results

Two factors were observed that may have impacted the results of this research: i) hand physiology of the participants and ii) perceived novelty of the robot. Three participants with very calloused fingers experienced difficulty with the touch-based interaction and had to use different, non-calloused fingers. Almost all participants had to be reminded to stay on task as they perceived the views obtained with the robot as novel, leading them to deviate at times into exploration when they were assigned specific tasks to complete.

8.6.1 Hand Physiology

The *Mission Specialist* interface was implemented on an Apple® iPad and uses touch-based interaction for input that requires the fingers of a user be able to provide a measurable difference in electrical capacitance at the surface of the screen. Conductive materials such as skin and metals (e.g., aluminum and silicon) provide a satisfactory difference in capacitance. Non-conductive materials, such as wood and plastic, do not provide a satisfactory difference in capacitance. There are no published minimum levels of capacitance by Apple® for human skin; however, it was observed during both the exploratory (1 participant) and experimental (2 participants) field studies that participants with very callused index fingers and/or thumbs had difficulty interacting. This was observed for payload camera tilt and zoom gestures (i.e., swipes and pinches) as well as simple touches (i.e., pressing the Capture Image button). The three participants with callused fingers deferred to using other fingers or parts of their hand that they normally would not swipe or touch with (e.g., a ring finger or a knuckle). When the participants were asked about this observation, all indicated that the lack of finger recognition was actually a common problem with other non-Apple® touch-based devices and that they had just adapted accordingly. As such, the three participants with very callused fingers could have produced results with the *Mission Specialist* interface that would not be as good as if they did not have the cal-

luses. This could be a limiting factor with touch-based devices in general; research on this issue should be explored.

8.6.2 Novelty of the Robot

Another factor that may have influenced participant performance was the perceived novelty of the robot. Very few organized groups of specialized responders (e.g., Texas Task Force 1) have in their cache of equipment a micro UAV. None of the participants in either the exploratory or experimental studies had significant exposure or immediate access to this type of technology. There was an anecdotally observed *wow* factor exhibited by almost all of the participants. During the two flights participants had to be kept on task and not be allowed to deviate into self-exploration with the payload camera. A common example of this was when participants were asked to identify any product or materials that had been spilled, some would deviate from looking for spills and instead look for placards on the derailed cars containing information about what was in the car because they thought that would be more important in a HAZMAT situation than finding spilled product. For an exploratory study, this would be fine but for an evaluation task under experimental conditions this type of deviation may have led to, for example, the high degree of variability recorded for task completion time. The most appropriate recommendation for this impact factor (for both experimental studies and real world application of a micro UAS) would be to have a clearly defined mission plan determined before the flight. Since the flight time for a micro UAV is only between 10- to 20-minutes maximum, deviation into an exploration process may utilize the robot resource in a sub-optimal manner, regardless of interface condition.

8.7 Summary

This section discussed the experimental field study results, described three trends from the collected data, and identified two factors that may have impacted the result outcomes.

The results from this dissertation research showed command-level experience and perceived responsibility for the robot affect interface preference, there are two dimensions to the Shared Roles Model for mUAS (*Mission Specialist* control and focused visual common ground), and hand physiology and robot novelty may have impacted the results.

9. CONCLUSIONS AND FUTURE WORK

This research determined that a *Mission Specialist* in a mUAS requires a role-specific, visual common ground interface permitting shared control of the payload camera and verbal coordination with the *Pilot*. Results from field experiments with 26 responders from the CBRN domain without mUAS experience showed that a *Mission Specialist* using the role-specific interface reported greater role empowerment while completing similar tasks in the same amount of time and experiencing the same level of stress as when passively viewing and instructing the *Pilot* for payload camera control. The most significant findings were that the work experience of a *Mission Specialist* and their perceived responsibility for the robot will influence the preferred interface for HRI mUAS. The role-specific interface is the most appropriate for an *ad hoc Mission Specialist*, regardless of work experience and perceived responsibility, as it permits both direct control of the payload camera and verbal coordination with the *Pilot*.

9.1 Significant Contributions and Conclusions

This section presents the significant theoretical and practical contributions from this research. There are three theoretical contributions that include: i) a link established between the Shared Roles Model and the field of human-computer interaction, ii) a new analysis method for human-robot interaction, and iii) an empirical determination that the *Mission Specialist* wants a *Pilot*. There are also three practical contributions of this work. They include: i) the importance of having untrained CBRN domain experts as participants in this research, ii) an empirical demonstration that HRI design requires ethnographic investigation, and iii) the development of a *Mission Specialist* interface. The theoretical contributions address concerns primarily of importance to the HRI research community. The practical contributions address issues mostly of importance to HRI practitioners.

9.1.1 Theoretical Contributions

This research made three significant theoretical contributions: i) a linkage between the Shared Roles Model and HCI now exists through the instantiation of the payload telefactor, ii) a new method of analysis is now available for human-robot interaction studies, and iii) an empirical determination that the *Mission Specialist* wants a *Pilot*. Each theoretical contribution is discussed in context of the research results and discussion, indicating primary stakeholders and beneficiaries, and provides where appropriate the broader impacts for the HRI and CBRN communities.

9.1.1.1 Linkage Between the Shared Roles Model and HCI

The *Mission Specialist* interface as an instantiation of the UAV payload telefactor connects the Shared Roles Model to HCI. This linkage is important for two reasons: i) it is the first time the payload telefactor abstraction in the Shared Roles Model has had a physical and testable form, and ii) that HCI-based principles can be successfully translated to physically-based interaction between a human and a robot operating as part of a human-robot team. The research result that the *Mission Specialist* perceived the robot and interface as providing similar security, loyalty, and support (versus the *Pilot*) may suggest that *Mission Specialist* views the interface as the robot itself. If this is true, it would empirically support the Shared Roles Model assumption that the robot and humans are in fact co-agents operating as a JCS and that this was accomplished through the integration of HCI principles. It would be of value to the HRI community to investigate the extent of association between a robot and its payload telefactor with regard to perceived co-agency by the *Mission Specialist*. Of additional significant interest is the question, what impact does co-location with the robot have on perceived co-agency? In the CBRN domain where in the future an untrained expert occupying the *Mission Specialist* role may not necessarily be co-located, understanding the extent of perceived co-agency may help inform individual and team performance and process expectations.

9.1.1.2 New Method of Analysis for HRI

This research presented a new method of analysis for HRI by demonstrating use of the Shared Roles Model to analyze the *Mission Specialist* role in mUAS. Use of the Shared Roles Model allowed the first focused study of the *Mission Specialist* role for a mUAS; it was also the first of its kind for any UAS. The ability to focus on an individual human role (or the entire human-robot team) benefits HRI researchers investigating UAS and any other unmanned systems. Demonstration of this new method of analysis for HRI provides a framework for scientific insight for the study of other roles, such as the *Pilot*. Understanding hidden dependencies, contentions, etc. that the Shared Roles Model has been shown through this work to reveal for mUAS, UAV designers and developers will have an additional perspective to existing UAV technology (e.g., the use of only one payload camera) and will be able to improve upon existing and future interfaces and platforms.

9.1.1.3 The *Mission Specialist* Wants a Separate *Pilot* Role

The *Mission Specialist* engaged in verbal coordination with the co-located *Pilot* role even if they preferred to have active control of the robot's payload camera. The greater trust towards and perceived support by the *Pilot* versus the robot, as reported by the *Mission Specialist*, implies that the physical presence of a separate *Pilot* role is necessary for the *Mission Specialist* to feel sufficiently confident and comfortable interacting with the robot. This is important as a *Mission Specialist* on an *ad hoc* team may have had little exposure or training with the robot, unlike the *Pilot* who is usually an expert trained on a specific UAV platform. It is not known if the verbal coordination preferred by the *Mission Specialist* has any impacts (e.g., stress, workload, etc.) on the *Pilot* role. Because mUAS human-robot teams in the CBRN domain will likely be *ad hoc*, it is expected that verbal coordination will vary based on i) the mission planning specific to the incident, and ii) the person filling the *Mission Specialist* role. Further research needs to be conducted to assess any potential impacts on the *Pilot* role resulting from varying degrees of verbal

coordination with the *Mission Specialist*. The most important open questions arising from this theoretical contribution are: would *Mission Specialist* empowerment (e.g., confidence, comfort, etc.) be affected and, if so, how would this impact performance, if the *Pilot* role were a software agent, the robot itself, or simply remotely-located?

9.1.2 Practical Contributions

There were three significant practical contributions resulting from this research: i) participation and an archival data set from specialized personnel who work the CBRN domain, ii) an exemplar for the importance for ethnographic investigation in HRI design, and iii) design recommendations, a computational architecture, and an implementation of the payload telefactor for the Shared Roles Model. Each practical contribution is discussed in context of the research results, indicating primary stakeholders and beneficiaries, and provides where appropriate the broader impacts for the HRI and CBRN communities.

9.1.2.1 Participation of Specialized Emergency Responders

Specialized personnel from the CBRN domain served as participants in this study and provided an archival data set for analysis. This is important for two reasons: i) authenticity of the research results, and ii) well informed design feedback. There have not been any CBRN-related UAS studies that have used actual CBRN personnel in their studies for data collection. As such, it is uncertain if the experimental results for role-specific interfaces found by other researchers [65] using participants with no domain experience are valid. The authenticity of the data collected through this research strengthen the case for adoption of UAV technology by personnel in the CBRN domain, especially since the responders were untrained with mUAS. Therefore, the design of the interface itself and data that were collected are unique to CBRN in ways that no other previous UAS study has been before.

9.1.2.2 HRI Design Requires Ethnographic Investigation

This research empirically showed that theoretical considerations do not always translate to effective practice and instead require ethnographic investigations with domain experts. Without the exploratory and experimental study results it would not have been possible to determine the hidden dependencies and effects of interface specialization that the Shared Roles Model revealed. The literature and technology findings were not sufficient enough to make this determination, nor would an evaluation of the interface with non-domain experts have provided information about the *Commander Effect* and the *Responsibility Effect*. Each of these empirical results were necessary to answer the main research question in an appropriate manner that a theoretical approach or data from related studies or non-experts could not. Ethnographic investigations should be used by HRI researchers and practitioners as domain-specific observations and data are necessary to help shape the final design in HRI.

9.1.2.3 Creation of a *Mission Specialist* Interface

Five recommended design guidelines, a computational architecture, and an implementation for a role-specific *Mission Specialist* interface for a micro UAS (or any UAS) are the available because of this research. The *Mission Specialist* interface is an example of rapid prototyping that could be used by either responders or researchers now, with the long term advantage of expanded use for different HRI studies and the creation of new knowledge. The role-specific *Mission Specialist* interface is also an example of rapid prototyping. The impacts on unmanned systems technology from this dissertation work include potential new employment opportunities for software engineers and unmanned systems developers, who will have access to the recommended design guidelines and interface software from which to propose new applications for HRI, as well as CBRN. It is recommended that this interface and its supporting principles be the standard method of human-robot interaction for a *Mission Specialist* in mUAS.

9.2 Future Work

There are both immediate and long-term research goals for which this dissertation work can be extended for mUAS. The immediate research goals proposed here address additional analyses of the video and post-assessment survey data to better understand team process and performance. Long-term research goals focus on questions that will require further investigation, most likely on a five-year time horizon or longer.

9.2.1 Immediate Future Research Goals

A very important immediate research goal that can be addressed in less than five years is analyzing the video data to evaluate overall team performance in the context of the role-specific *Mission Specialist* interface. It may be possible to discern levels of stress experience by the *Pilot* role through evaluating confusion in the verbal dialog. Likewise, role collision can likely be evaluated. Shorter-term research studies could be developed to measure stress on the *Pilot*. An important short-term open question that remains is: what factors associated with the mission and/or what conditions in the environment caused control to be ceded to the *Pilot* even when the *Mission Specialist* preferred to control the payload camera?

9.2.2 Long-Term Future Research Goals

Summative experiments with longer, more complete scenarios and measuring *Mission Specialist* and *Pilot* biometrics may provide insight for micro UAS team performance. Individual and joint situation awareness studies should be developed to non-invasively measure micro UAS team process. Given the length of the experiments required for this dissertation work on individual *Mission Specialist* role performance, individual and joint studies for situation awareness are more likely to be on a much longer time horizon. One

long-term open question is: what other forms of visual communication are important for a role-specific *Mission Specialist* interface?

REFERENCES

- [1] L. R. Newcome. *Unmanned Aviation: A Brief History of Unmanned Aerial Vehicles*, Reston, VA: American Institute of Aeronautics and Astronautics, 2004.
- [2] N. J. Cooke and H. K. Pedersen. "Unmanned aerial vehicles," In J.A. Wise, V.D. Hopkin, and D.J. Garland, editors, *Handbook of Aviation Human Factors*, 2nd Edition, pp. 18.1-18.8, Boca Raton, FL: CRC Press, 2010.
- [3] R. R. Murphy, E. Steimle, C. Griffin, M. Hall, and K. Pratt, "Cooperative use of unmanned sea surface and micro aerial vehicle at Hurricane Wilma," *Journal of Field Robotics*, vol. 25, no. 1-2, pp. 164-180, 2008.
- [4] M. A. Goodrich, B. S. Morse, D. Gerhardt, J. L. Cooper, J. Adams, C. Humphrey, and M. Quigley, "Supporting wilderness search and rescue using a camera-equipped UAV," *Journal of Field Robotics*, vol. 25, no. 1-2, pp. 89-110, 2009.
- [5] J. A. Adams, C. M. Humphrey, M. A. Goodrich, J. L. Cooper, B. S. Morse, C. Engh, and N. Rasmussen, "Cognitive task analysis for developing unmanned aerial vehicle wilderness search support," *Journal of Cognitive Engineering and Decision Making*, vol. 3, no. 1, pp. 1-26, 2009.
- [6] B. T. Schreiber, D. R. Lyon, E. L. Martin, and H. A. Confer, "Impact of prior flight experience on learning Predator UAV operator skills," United States Air Force Research Laboratory Report AFRL-HE-AZ-TR-2002-0026, 2002.
- [7] J. Blazakis, "Border security and unmanned aerial vehicles," CRS Report for the United States Congress, Order Code RS21691, January 2004.
- [8] R. M. Taylor, "Human automation integration for supervisory control of UAV's," in *Proc. of the Virtual Media for Military Applications*, Meeting Proceedings RTO-MP-HFM-136, pp. 12.1-12.10, 2006.
- [9] D.A. Fulghum. (2005, August 15) "New technology promises leaps in UAV warfighting capability," *Aviation Week*. [Online]. Available: http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=awst&id=news/08155p02.xml&headline=New%20Technology%20Promises%20Leaps%20in%20UAV%20Warfighting%20Capability.
- [10] J. R. Wilson. (2002, July) "UAVs and the human factor," *Aerospace America*. [Online]. Available: <http://www.aiaa.org/aerospace/Article.cfm?issuetocid=233&ArchiveIssueID=28>.
- [11] A. Rango, A. Laliberte, J. E. Herrick, C. Winters, and K. Havstad. "Development of an operational UAV/remote sensing capability for rangeland management," in *Proc. of the Twenty-Third International UAV Conference*, 2008.
- [12] L. C. Trost. "Unmanned air vehicles (UAVs) for cooperative monitoring," Sandia National Laboratories Report SAND2000-0185, 2000.

- [13] R. C. Hruska, G. D. Lancaster, J. L. Harbour, and S. J. Cherry. "Small UAV-acquired, high resolution, georeferenced still imagery," Idaho National Laboratory Report INL/CON-05-00235, 2005.
- [14] L. F. Johnson, S. Herwitz, S. Dunagan, B. Lobitz, D. Sullivan, and R. Slye. "Collection of ultra high spatial and spectral resolution image data over California vinyards with a small UAV," in *Proc. of the International Symposium on Remote Sensing of the Environment*, 2003.
- [15] M. J. Barnes, B. G. Knapp, B. W. Tillman, B. A. Walters, and D. Velicki. "Crew systems analysis of unmanned aerial vehicle (UAV) future job and tasking environments," United States Army Research Laboratory Report TR-2081, 2000.
- [16] N. J. Cooke, H. K. Pederson, O. Connor, J. C. Gorman, and D. Andrews. "Acquiring team-level command and control skill for UAV operation," in N. J. Cooke, H. L. Pringle, H. K. Pedersen, and O. Connor, editors, *Human Factors of Remotely Operated Vehicles*, vol. 7, pp. 285-297, New York, NY: Elsevier, 2006.
- [17] M.A. Goodrich, J. Cooper, J. A. Adams, C. Humphrey, R. Zeeman, and B. G. Buss. "Using a mini-UAV to support wilderness search and rescue: Practices for human-robot teaming," in *Proc. of the IEEE International Workshop on Safety, Security, and Rescue Robots*, pp. 1-6, 2007.
- [18] R. R. Murphy, K. S. Pratt, and J. L. Burke. "Crew roles and operational protocols for rotary-wing -UAVs in close urban environments," in *Proc. of the Third ACM/IEEE International Conference on Human-Robot Interaction*, pp. 73-80, 2008.
- [19] C. E. Rash, P. A. LeDuc, and S. D. Manning. "Human factors in U.S. military unmanned aerial vehicle accidents," in N. J. Cooke, H. L. Pringle, H. K. Pedersen, and O. Connor, editors, *Human Factors of Remotely Operated Vehicles*, vol. 7, pp. 117-131, New York, NY: Elsevier, 2006.
- [20] R. R. Murphy and J. L. Burke. "From remote tool to shared roles," in *IEEE Robotics and Automation Magazine, special issue on New Vistas and Challenges for Teleoperation*, vol. 15, no. 4, pp. 39-49, 2008.
- [21] J. Cooper and M. A. Goodrich. "Towards combining uav and sensor operator roles in UAV-enabled visual search," in *Proc. of the Third ACM/IEEE International Conference on Human-Robot Interaction*, pp. 351-358, 2008.
- [22] M. L. Cummings and P. J. Mitchell. "Managing multiple uavs through a timeline display," in *Proc. of the American Institute of Aeronautics and Astronautics Infotech@Aerospace*, September 2005.
- [23] M. L. Cummings, S. Bruni, S. Mercier and P. J. Mitchell. "Automation architecture for single operator-multiple uav command and control," *The International C2 Journal*, vol. 1, no. 2, pp. 1-24, 2007.
- [24] A. Burkle, F. Segor and M. Kollmann. "Toward autonomous micro uav swarms," *Journal of Intelligent and Robotic Systems*, vol. 61, no. 1-4, pp. 339-353, 2011.
- [25] J. G. Manathara, P. B. Sujit and R. W. Beard. "Multiple uav coalitions for a search and prosecute mission," *Journal of Intelligent and Robotic Systems*, vol. 62, no. 1, pp. 125-358, 2011.

- [26] A. Tsourdos, B. A. White and M. Shanmugavel. *Cooperative Path Planning of Unmanned Aerial Vehicles*, Hoboken, NJ: John Wiley and Sons, Inc., 2011.
- [27] Parrot. (2011) Parrot AR.Drone User Guide. [Online]. Available: http://www.parrot.com/fr/support/guidesutilisateur/ar.drone_user-guide_uk.pdf.
- [28] A. Hobbs. "Unmanned aircraft systems," In E. Salas and D. Maurino, editors, *Human Factors in Aviation*, 2nd Edition, pp. 505-531, New York, NY: Elsevier, 2010.
- [29] A. P. Tvaryanas. "Human systems integration in remotely piloted aircraft operations," *Aviation, Space, and Environmental Medicine*, vol. 77, no. 12, pp. 1278-1282, 2006.
- [30] B. Walters and M. J. Barnes. "Modeling the effects of crew size and crew fatigue on the control of tactical unmanned aerial vehicles (UAVs)", in *Proc. of the Winter Simulation Conference*, pp. 920-924, 2000.
- [31] N. J. Cooke and R. A. Chadwick. "Lessons learned from human-robotic interactions on the ground and in the air," in M. Barnes and F. Jentsch, editors, *Human-Robot Interaction in Future Military Operations*, pp. 355-372, London, UK: Ashgate, 2010.
- [32] J. M. Peschel and R. R. Murphy. "Mission specialist interfaces in unmanned aerial systems," in *Proc. of the Sixth ACM/IEEE International Conference on Human-Robot Interaction*, pp. 225-226, 2011.
- [33] R. Hopcroft, E. Burchat, and J. Vince. "Unmanned aerial vehicles for maritime patrol: human factors issues," Australian Defence Science and Technology Organisation Report DSTO-GD-0463, 2006.
- [34] W. Bierbaum. (1995) "UAVs," *Air and Space Power Journal Archives*. [Online]. Available: <http://www.airpower.maxwell.af.mil/airchronicles/cc/uav.html>.
- [35] United States Air Force. "United States Air Force unmanned aircraft systems flight plan 2009-2047," [Online]. Available: <http://www.defense.gov/dodcmsshare/briefingslide/339/090723-D-6570C-001.pdf>.
- [36] United States Army. "U.S. Army unmanned aircraft systems roadmap 2010-2035," [Online]. Available: <http://www.fas.org/irp/program/collect/uas-army.pdf>.
- [37] Office of the United States Secretary of Defense. "Unmanned aircraft system roadmap 2005-2030," [Online]. Available: http://www.fas.org/irp/program/collect/uav_roadmap2005.pdf.
- [38] J. L. Burke, "RSVP: an investigation of the effects of remote shared visual presence on team process and performance in US&R teams," Ph.D. Dissertation, University of South Florida, April 2006.
- [39] K. Pratt, R. R. Murphy, J. L. Burke, J. Craighead, C. Griffin and S. Stover. "Use of tethered small unmanned aerial system at Berkman Plaza II collapse," in *Proc. of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2008.
- [40] R. R. Muprhy. "Human-robot interaction in rescue robotics," *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews*, vol. 34, no. 2, pp. 138-153, 2004.

- [41] G. Hoffman and C. Breazeal. "Collaboration in human-robot teams," in *Proc. of the First AIAA Intelligent Systems Technical Conference*, pp. 18, 2004.
- [42] D. D. Woods and E. Hollnagel, *Joint Cognitive Systems: Patterns in Cognitive Systems Engineering*, Boca Raton, FL: CRC Press, 2006.
- [43] M. Nas. "The changing face of the interface: an overview of UAS control issues and controller certification," Unmanned Aircraft Technology Applications Research (UATAR) Working Group 27, 2008.
- [44] J. L. Weeks. "Unmanned aerial vehicle operator qualifications," United States Air Force Research Laboratory Report AFRL-HE-AZ-TR-2000-2002, 2000.
- [45] T. Oron-Gilad and Y. Minkov. "Remotely operated vehicles (ROVs) from the bottom-up operational perspective," In M. Barnes and F. Jentsch, editors, *Human-Robot Interaction in Future Military Operations*, pp. 211-227, London, UK: Ashgate, 2010.
- [46] Skybotix Technologies. (2011) CoaX®Coaxial Helicopter Product Information Sheet. [Online]. Available: <http://www.skybotix.com>.
- [47] AirRobot. (2010) AirRobot AR100B®Product Information Sheet. [Online]. Available: <http://www.airrobot-uk.com/air-robot-products.htm>.
- [48] Draganfly Innovations, Inc. (2011) Draganflyer X Series Product Information. [Online]. Available: <http://www.draganfly.com/industrial/products.php>.
- [49] Aeryon Labs, Inc. (2011) Scout Product Information Sheet. [Online]. Available: <http://www.aeryon.com/products/avs.html>.
- [50] J. A. Jacko and A. Sears. *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications*. Mahwah, NJ: Lawrence Erlbaum Associates, 2003.
- [51] A. Dix, J. Finlay, G. Abowd and R. Beale. *Human-Computer Interaction*, 2nd Edition. London, UK: Prentice Hall Europe, 1998.
- [52] B. Schneiderman and C. Plaisant. *Designing the User Interface: Strategies for Effective Human-Computer Interaction*, 5th Edition. New York, NY: Addison-Wesley, 2010.
- [53] H. Sharp, Y. Rogers and J. Preece. *Interaction Design: Beyond Human-Computer Interaction*, 2nd Edition. West Sussex, England: John Wiley & Sons, Ltd., 2007.
- [54] D. A. Norman. *The Design of Everyday Things*. New York, NY: Basic Books, 2002.
- [55] S. Few. *Information Dashboard Design: The Effective Visual Communication of Data*. Sebastopol, CA: O'Reilly Media, Inc., 2006.
- [56] M. R. Endsley, B. Bolte and D. G. Jones. *Designing for Situation Awareness: An Approach to User-Centered Design*. New York, NY: Taylor & Francis, Inc., 2003.

- [57] B. Mutlu, S. Osman, J. Forlizzi, J. Hodgins and S. Kiesler. "Task structure and user attributes as elements of human-robot interaction design," in *Proc. of the Fifteenth IEEE International Symposium on Robot and Human Interactive Communication*, pp. 74-79, 2006.
- [58] J. A. Adams. "Human-robot interaction design: Understanding user needs and requirements," in *Proc. of the Forty-Ninth Annual Meeting of the Human Factors and Ergonomics Society*, pp. 447-451, 2006.
- [59] A. Steinfeld, T. Fong, D. Kaber, M. Lewis, J. Scholtz, A. Schultz and M. Goodrich. "Common metrics for human-robot interaction," in *Proc. of the First ACM/IEEE International Conference on Human-Robot Interaction*, pp. 33-40, 2006.
- [60] M. A. Goodrich and D. R. Olsen, Jr. "Seven principles of efficient human-robot interaction," in *Proc. of the IEEE International Conference on Systems, Man and Cybernetics*, vol. 4, pp. 3942-3948, 2003.
- [61] J. M. Riley, L. D. Strater, S. L. Chappell, E. S. Connors and M. R. Endsley. "Situation awareness in human-robot interaction: Challenges and user interface requirements," In M. Barnes and F. Jentsch, editors, *Human-Robot Interaction in Future Military Operations*, pp. 171-192, London, UK: Ashgate, 2010.
- [62] Willow Garage. (2011) "OpenCV (Open Source Computer Vision) Wiki". [Online]. Available: <http://opencv.willowgarage.com>.
- [63] C. L. Bethel and R. R. Murphy, "Review of human studies methods in HRI and recommendations," *International Journal of Social Robotics*, vol. 2, no. 4, pp. 347-359, 2010.
- [64] J. Sauro and J. R. Lewis. "Average task times in usability tests: what to report?," in *Proc. of the 28th International Conference on Human Factors in Computing Systems (CHI '10)*, 2010.
- [65] C.M. Humphrey. "Information abstraction visualization for human-robot interaction," Ph.D. Dissertation, Vanderbilt University, August 2009.

APPENDIX A**VERBAL ANNOUNCEMENT SCRIPT**

Welcome the prospective participant(s) and introduce yourself. State that you are speaking to the individual (or group) to solicit volunteers to participate in a study on the use of mobile touch-based devices (Apple iPads®) for unmanned aerial systems. Determine whether or not the individual (or group) wishes to be considered as a prospective participant. If no, thank the individual (or group) and end the discussion. If yes, proceed with the rest of this verbal announcement.

Issue a copy of the Information Form (Appendix B) to the individual (or group). Read the information contained on the Information Form aloud to the individual (or group). At the end of reading aloud, ask for any questions about the information that has been read. If the prospective participant(s) do not wish to participate, thank the individual (or group) and end the discussion. If yes, proceed with the rest of this verbal announcement.

Issue a copy of the Consent Form (Appendix C). Read the information contained on the Consent Form aloud to the individual (or group). At the end of reading aloud, ask for any questions about the information that has been read. If the prospective participant(s) do not wish to participate, thank the individual (or group) and end the discussion. If yes, obtain signature(s) on the Consent Form(s) and proceed to the Mission Script (Appendix F).

APPENDIX B

EXPLORATORY STUDY INFORMATION SHEET

IRB Version 06/09/11

Introduction

The purpose of this form is to provide you (as a prospective research study participant) information that may affect your decision as to whether or not to participate in this research.

You have been asked to participate in a research study that examines the individual performance of a human interacting with an unmanned aerial vehicle (UAV). The purpose of this study is to evaluate an Apple iPad® application we have developed that will allow you to view real-time video from a UAV and capture images of pre-determined objects. You were selected to be a possible participant because you have experience as a specialized emergency responder and/or are a roboticist who develops search and rescue robotics technology.

What will I be asked to do?

If you agree to participate in this study, you will be asked to 1) complete a pre-study background survey and short training meeting, 2) watch a video feed on an Apple iPad® or a laptop computer and interact with the UAV camera to capture images from the video of pre-determined objects when they become visible, and 3) complete a post-study survey. This study will take approximately 1-hour to complete.

Your participation will be video recorded with audio.

What are the risks involved in this study?

The risks associated with this study are minimal, and are not greater than risks ordinarily encountered in daily life.

What are the possible benefits of this study?

The possible benefits of participation are that you will gain experience working with a UAV in a high-fidelity search and rescue exercise that uses cutting-edge robotics technology.

Do I have to participate?

No. Your participation is voluntary. You may decide not to participate or to withdraw at any time without your current or future relations with Texas A&M University (or any related System affiliates) being affected.

Who will know about my participation in this research study?

This study is confidential and the records of this study will be kept private. No identifiers linking you to this study will be included in any sort of report that might be published. Research records will be stored securely and only Dr. Robin R. Murphy and Mr. Joshua Peschel will have access to the records.

If you choose to participate in this study, you will be video recorded with audio. Any audio/video recordings will be stored securely and only Dr. Robin R. Murphy and Mr. Joshua Peschel will have access to the recordings. Any recordings will be kept for 3-years and then erased.

Is there anything else I should consider?

The researchers can choose to end the experiment at any time.

Whom do I contact with questions about the research?

If you have questions regarding this study, you may contact Dr. Robin R. Murphy, (979) 845-2015, murphy@cse.tamu.edu or Mr. Joshua Peschel, (979) 324-0985, peschel@tamu.edu.

Whom do I contact about my rights as a research participant?

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979) 458-4067 or irb@tamu.edu.

Participation

Please be sure you have read the above information, asked questions and received answers to your satisfaction. If you would like to be in the study, please refer to and sign the consent form.

APPENDIX C

EXPLORATORY STUDY CONSENT FORM

IRB Version 06/09/11

Introduction

The purpose of this form is to provide you information that may affect your decision as to whether or not to participate in this research study. If you decide to participate in this study, this form will also be used to record your consent.

You have been asked to participate in a research project study that examines the individual performance of a human interacting with an unmanned aerial vehicle (UAV). The purpose of this study is to evaluate an Apple iPad® application we have developed that will allow you to view real-time video from a UAV and capture image of pre-determined objects. You were selected to be a possible participant because you have experience as a specialized emergency responder and/or are a roboticist who develops search and rescue robotics technology.

What will I be asked to do?

If you agree to participate in this study, you will be asked to 1) complete a pre-study background survey and short training meeting, 2) watch a video feed on an Apple iPad® or a laptop computer and interact with the UAV camera to capture images from the video of pre-determined objects when they become visible, and 3) complete a post-study survey. This study will take approximately 1-hour to complete.

Your participation will be video recorded with audio.

What are the risks involved in this study?

The risks associated with this study are minimal, and are not greater than the risks ordinarily encountered in daily life.

What are the possible benefits of this study?

The possible benefits of participation are that you will gain experience working with a UAV in a high-fidelity search and rescue exercise that uses cutting-edge robotics technology.

Do I have to participate?

No. Your participation is voluntary. You may decide not to participate or to withdraw at any time without your current or future relations with Texas A&M University (or any

related System affiliates) being affected.

Who will know about my participation in this research study?

This study is confidential and the records of this study will be kept private. No identifiers linking you to this study will be included in any sort of report that might be published. Research records will be stored securely and only Dr. Robin R. Murphy and Mr. Joshua Peschel will have access to the records.

If you choose to participate in this study, you will be video recorded with audio. Any audio/video recordings will be stored securely and only Dr. Robin R. Murphy and Mr. Joshua Peschel will have access to the recordings. Any recordings will be kept for 3-years and then erased.

Is there anything else I should consider?

The researchers can choose to end the experiment at any time.

Whom do I contact with questions about the research?

If you have questions regarding this study, you may contact Dr. Robin R. Murphy, (979) 845-2015, murphy@cse.tamu.edu or Mr. Joshua Peschel, (979) 324-0985, peschel@tamu.edu.

Whom do I contact about my rights as a research participant?

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979) 458-4067 or irb@tamu.edu.

Signature

Please be sure you have read the above information, asked questions and received answers to your satisfaction. You will be given a copy of the consent form for your records. By signing this document, you consent to participate in this study.

Signature of Participant: _____ Date: _____

Printed Name: _____

Signature of Person Obtaining Consent: _____ Date: _____

Printed Name: _____

APPENDIX D**EXPLORATORY STUDY PRE-ASSESSMENT**

Please answer the following survey questions. All information is confidential and will be used for research purposes only.

Question 1: What is your age?

- (a) Under 25-years
- (b) 25-years to 34-years
- (c) 35-years to 44-years
- (d) 45-years to 54-years
- (e) 55-years and older

Question 2: What is your gender?

- (a) Male
- (b) Female

Question 3: Have you ever used a mobile touch-based device (e.g., Apple iPhone® or iPad®) before?

- (a) Yes
- (b) No

Question 4: If you answered ‘Yes’ to Question 3, how long have you used mobile touch-based devices? If you answered ‘No’ to Question 3, please skip to Question 7.

- (a) 0 to 6-months
- (b) 6- to 12-months
- (c) More than 1-year
- (d) More than 2-years
- (e) More than 3-years

Question 5: If you answered ‘Yes’ to Question 3, how often do you use mobile touch-based devices? If you answered ‘No’ to Question 3, please skip to Question 7.

- (a) Continuously throughout every day
- (b) A few times per week
- (c) A few times per month
- (d) A few times per year

Question 6: If you answered ‘Yes’ to Question 3, in what context to you typically interact with mobile touch-based devices? If you answered ‘No’ to Question 3, please skip to Question 7. This question can have more than one answer.

- (a) I use it as my phone
- (b) I use it to play games
- (c) I use it to surf the Internet
- (d) I use it to check email
- (e) I do not own a device but I borrow from others

Question 7: Have you ever used a Tablet PC or other electronic pen-based device before?

- (a) Yes
- (b) No

Question 8: If you answered ‘Yes’ to Question 1, how long have you used a Tablet PC or other electronic pen-based devices? If you answered ‘No’ to Question 7, please skip to Question 11.

- (a) 0 to 6-months
- (b) 6- to 12-months
- (c) More than 1-year
- (d) More than 2-years
- (e) More than 3-years

Question 9: If you answered ‘Yes’ to Question 7, how often do you use a Tablet PC or other electronic pen-based devices? If you answered ‘No’ to Question 7, please skip to Question 11.

- (a) Continuously throughout every day
- (b) A few times per week
- (c) A few times per month
- (d) A few times per year

Question 10: If you answered ‘Yes’ to Question 7, in what context to you typically interact with a Tablet PC or other electronic pen-based devices? If you answered ‘No’ to Question 7, please skip to Question 11. This question can have more than one answer.

- (a) I use it as my primary computer
- (b) I use it to play games
- (c) I use it to surf the Internet
- (d) I use it to check email
- (e) I do not own a device but I borrow from others

Question 11: How often do you play video games?

- (a) Continuously throughout every day
- (b) A few times per week
- (c) A few times per month
- (d) A few times per year
- (e) I do not play video games

Question 12: If you do play video games, how often do you play first-person action games (e.g., Quake, HalfLife, etc.)?

- (a) Continuously throughout every day
- (b) A few times per week
- (c) A few times per month
- (d) A few times per year
- (e) I do not play first-person simulation games

Question 13: Have you ever controlled a camera remotely before (e.g., on a robot or through the Internet)?

- (a) Yes
- (b) No

Question 14: If you answered 'Yes' to Question 13, please briefly describe the situation(s) in which you have controlled a camera remotely before.

Question 15: Have you ever participated in a search and rescue mission before?

- (a) Yes
- (b) No

Question 16: If you answered 'Yes' to Question 15, please briefly list and/or describe your role in the situation(s) in which you have participated in a search and rescue mission before.

Question 17: Have you ever participated in a robot-assisted search and rescue mission or exercise before?

- (a) Yes
- (b) No

Question 18: If you answered 'Yes' to Question 17, please briefly list and/or describe your role and the type of robot (e.g., air, ground, sea) in the situation(s) in which you have participated in a robot-assisted search and rescue mission before.

APPENDIX E

EXPLORATORY STUDY COMMAND PROTOCOLS

In the case of the mirrored display (The Control Trial) participants should only use the following verbal commands to instruct the *Pilot*:

Camera Controls:

Tilt Camera Up
Tilt Camera Down
Zoom Camera In
Zoom Camera Out
Take Photo

Vehicle Controls:

Turn Left ___ Degrees
Turn Right ___ Degrees

In the case of the controllable display (The Experimental Trial) participants should only use the following verbal commands to instruct the *Pilot*:

Vehicle Controls:

Turn Left ___ Degrees
Turn Right ___ Degrees

In the exploratory study, participants were instructed that the DraganFlyer™ X6 camera controls on the Apple iPad® were defined by the gestures as shown in Figure E.1.

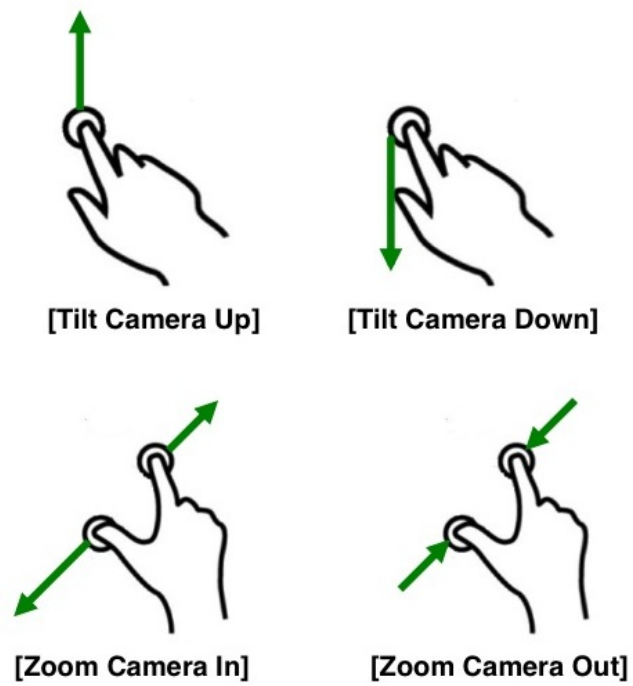


Fig. E.1. Gestures Used During the Exploratory Study for Apple iPad® Control of the DraganFlyer™ X6 Payload Camera (Courtesy of Center for Robot-Assisted Search and Rescue).

APPENDIX F

EXPLORATORY STUDY MISSION SCRIPT

Welcome the participants to the study. Introduce yourself and the other members of the research team. Obtain verbal confirmation from each participant that both the Information Sheet (Appendix B) has been received and read, and that the Consent Form (Appendix C) has been received, read, and signed.

In the case of the mirrored display (The Control Trial) say this:

You will be participating as part of an unmanned aerial system, which includes a human team and a micro unmanned aerial vehicle, for the purposes of investigating a simulated train derailment involving hazardous materials. Your team's mission is to fly a predetermined pattern over the accident scene to capture and interpret video that may aid other responders to deal with the accident.

Your role will be as the *Mission Specialist*. Your responsibilities are to watch the live video feed from the unmanned aerial vehicle camera on the *Mission Specialist* interface and verbally direct the *Pilot* to control the camera (tilt and zoom) and take photographs when an identified target becomes visible. During the mission you may refer to a quick reference sheet indicating commands you may give the *Pilot* for camera control. At various points in the mission, I will ask you one or more questions about a specific target that is being examined.

We will be recording the mission activities on video, therefore please speak clearly and loud enough to be recorded. We will also be monitoring your heart rate, so please do not interfere with or remove any of the monitoring equipment. If the equipment becomes uncomfortable at any time, please let me know and we will adjust it for you. If you have any questions about how to operate the *Mission Specialist* interface, I can answer those for you. However, I cannot answer any questions about the mission itself. Do you have any questions before we start?

In the case of the controllable display (The Experimental Trial) say this:

You will be participating as part of an unmanned aerial system, which includes a human team and a micro unmanned aerial vehicle, for the purposes of investigating a simulated train derailment involving hazardous materials. Your team's mission is to fly a predetermined pattern over the accident scene to capture and interpret video that may aid other responders to deal with the accident.

Your role will be as the *Mission Specialist*. Your responsibility is to watch the live video feed from the unmanned aerial vehicle camera, control the camera (tilt and zoom), and take pictures using the *Mission Specialist* interface when an identified target becomes visible. At various points in the mission, I will ask you one or more questions about a specific target that is being examined.

We will be recording the mission activities on video, therefore please speak clearly and loud enough to be recorded. We will also be monitoring your heart rate, so please do not interfere with or remove any of the monitoring equipment. If the equipment becomes uncomfortable at any time, please let me know and we will adjust it for you. If you have any questions about how to operate the *Mission Specialist* interface, I can answer those for you. However, I cannot answer any questions about the mission itself. Do you have any questions before we start?

When the participant finishes the mission, thank them for participating and direct them back to the main building.

APPENDIX G

EXPLORATORY STUDY SCRIPT FOR FLIGHT 1

Because every participant has to go through the same tasks and have the opportunity to see the same things in the same amount of time, we have to constrain how you would most likely use a UAV in practice or what different models of UAVs can do. We would be happy to talk with you about UAVs after the experiments.

For this experiment, the *Pilot* will go to a series of pre-specified waypoints and then you will answer a set of questions and get specific pictures. At each waypoint, the UAV will have to stay at the same altitude and can't move location. However, you can tell the *Pilot* to turn the UAV turn left or right (with the mirrored display, also add make the camera zoom in and out, and make the camera turn up and down).

The goal is to answer all the questions and get the pictures for all the waypoints within 7-minutes.

Provide verbal commands for either mirrored or controllable condition (Appendix F).

We will now begin Flight 1. You do not have to pay attention before we get to waypoint 1 or between waypoints.

Waypoint 1 [above tanker truck at 65-feet]:



Fig. G.1. Image Captured by the DraganFlyer™ X6 Payload Camera Illustrating the View from Waypoint 1 on Flight 1 (Courtesy of Center for Robot-Assisted Search and Rescue).

We are now at Waypoint 1 (Figure G.1). Please begin and remember to use the specific verbal commands to talk to the *Pilot*.

How many rail cars can you count? Remember you can turn, tilt, zoom.

Please obtain one photo that best captures the number of cars you see.

From this position, is there any product flowing or are there any exposure hazards you can identify? If so, what are they? And if yes please obtain one photo of each hazards or product you may identify.

Now we are moving to Waypoint 2.

Waypoint 2 [move backwards from tanker truck at 65-feet]:



Fig. G.2. Image Captured by the DraganFlyer™ X6 Payload Camera Illustrating the View from Waypoint 2 on Flight 1 (Courtesy of Center for Robot-Assisted Search and Rescue).

We are now at Waypoint 2 (Figure G.2).

Find the tanker truck.

Can you count the number of vents on the top of the tanker truck? If so, how many vents are there? Remember you can use zoom.

Please obtain one photo that best captures the number of vents you see.

Can you identify any punctures or ruptures to the tanker truck and if so, please obtain one photo of any puncture or ruptures you may see.

Now we are moving to Waypoint 3.

Waypoint 3 [move leftwards from tanker truck at 65-feet]:



Fig. G.3. Image Captured by the DraganFlyer™ X6 Payload Camera Illustrating the View from Waypoint 3 on Flight 1 (Courtesy of Center for Robot-Assisted Search and Rescue).

We are now at Waypoint 3 (Figure G.3).

Find the train engine.

Please identify and read the number off of the black engine car, and obtain one photo of the number on the black engine car.

We are done.

APPENDIX H

EXPLORATORY STUDY SCRIPT FOR FLIGHT 2

We will now begin Flight 2.

This will be a different set of waypoints and but the goal is the same: to get the pictures for all the waypoints in 7-minutes. The UAV will have the same constraints as before.

Provide verbal commands for either mirrored or controllable condition (Appendix F).

Remember, you do not have to pay attention before we get to waypoint or between waypoints.

Waypoint 1 [above gray tanker at 70-feet]:



Fig. H.1. Image Captured by the DraganFlyer™ X6 Payload Camera Illustrating the View from Waypoint 1 on Flight 2 (Courtesy of Center for Robot-Assisted Search and Rescue).

We are now at Waypoint 1 (Figure H.1). Please begin and remember to use the specific verbal commands to talk to the *Pilot*.

From this position, are there any exposure hazards that you can identify? If so, what are they and Please obtain one photo that best captures each hazard.

How many train cars can you count?

Please obtain one photo that best captures the number of cars you see.

Now we are moving to Waypoint 2.

Waypoint 2 [move backwards from gray tanker car at 70-feet]:



Fig. H.2. Image Captured by the DraganFlyer™ X6 Payload Camera Illustrating the View from Waypoint 2 on Flight 2 (Courtesy of Center for Robot-Assisted Search and Rescue).

We are now at Waypoint 2 (Figure H.2).

Find the overturned gray tanker car.

Please identify and read the chemical name printed on the overturned gray tanker car.

Please obtain one photo that best captures the chemical name you see.

Please identify and read the emergency telephone number printed on the overturned gray tanker car and obtain one or more photos that best captures the emergency telephone number you see.

Now we are moving to Waypoint 3.

Waypoint 3 [turn toward the black tanker cars at 70-feet]:

We are now at Waypoint 3 (Figure H.3).



Fig. H.3. Image Captured by the DraganFlyer™ X6 Payload Camera Illustrating the View from Waypoint 3 on Flight 2 (Courtesy of Center for Robot-Assisted Search and Rescue).

Find the black tanker cars.

Please identify and read the number off of the black tanker car sitting on top of the overturned black tanker car.

Please obtain one or more photos of the number on the black tanker car.

We are done.

APPENDIX I**EXPLORATORY STUDY POST-ASSESSMENT 1**

Please answer the following survey questions for the mirrored display trial. All information is confidential and will be used for research purposes only.

Question 1: How confident did you feel in your ability to instruct the *Pilot* to accurately move the camera up and down?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 2: How confident did you feel in your ability to instruct the *Pilot* to accurately zoom the camera in and out?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 3: How confident did you feel in your ability to instruct the *Pilot* to accurately take pictures?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 4: How comfortable did you feel asking the *Pilot* to move the camera up and down?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 5: How comfortable did you feel asking the *Pilot* to zoom the camera in and out?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 6: How comfortable did you feel asking the *Pilot* to accurately take pictures?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 7: How confident did you feel in your individual ability to accurately instruct the *Pilot* to acquire photos of the targets?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 8: How comfortable did you individually feel instructing the *Pilot* to acquire photos of the targets?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 9: How confident did you feel in your team's ability to accurately acquire photos of the targets when instructing the *Pilot*?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 10: How comfortable did you feel in your team's ability to acquire photos of the targets when instructing the *Pilot*?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

APPENDIX J**EXPLORATORY STUDY POST-ASSESSMENT 2**

Please answer the following survey questions for the controllable display trial. All information is confidential and will be used for research purposes only.

Question 1: How confident did you feel in your ability to accurately move the camera up and down with the touch interface?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 2: How confident did you feel in your ability to accurately zoom the camera in and out with the touch interface?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 3: How confident did you feel in your ability to accurately take pictures with the touch interface?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 4: How comfortable did you feel with the gesture to move the camera up and down with the touch interface?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 5: How comfortable did you feel with the gesture to zoom the camera in and out with the touch interface?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 6: How comfortable did you feel with the gesture to take pictures with the touch interface?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 7: How confident did you feel in your individual ability to accurately acquire photos of the targets using the touch interface?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 8: How comfortable did you individually feel in using the touch interface to acquire photos of the targets?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 9: How confident did you feel in your team's ability to accurately acquire photos of the targets when using the touch interface?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 10: How comfortable did you feel in your team's ability to acquire photos of the targets when using the touch interface?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

APPENDIX K

EXPERIMENTAL STUDY INFORMATION SHEET

IRB Version 01/24/12

Introduction

The purpose of this form is to provide you (as a prospective research study participant) information that may affect your decision as to whether or not to participate in this research.

You have been asked to participate in a research study that examines the individual performance of a human interacting with an unmanned aerial vehicle (UAV). The purpose of this study is to evaluate an Apple iPad® application we have developed that will allow you to view real-time video from a UAV and capture images of pre-determined objects. You were selected to be a possible participant because you have experience as a specialized emergency responder and/or are a roboticist who develops search and rescue robotics technology.

What will I be asked to do?

If you agree to participate in this study, you will be asked to 1) complete a pre-study background survey and short training meeting, 2) watch a video feed on an Apple iPad® or a laptop computer and interact with the UAV camera to capture images from the video of pre-determined objects when they become visible, and 3) complete a post-study survey. This study will take approximately 2-hours to complete.

Your participation will be video recorded with audio.

What are the risks involved in this study?

The risks associated with this study are minimal, and are not greater than risks ordinarily encountered in daily life.

What are the possible benefits of this study?

The possible benefits of participation are that you will gain experience working with a UAV in a high-fidelity search and rescue exercise that uses cutting-edge robotics technology.

Do I have to participate?

No. Your participation is voluntary. You may decide not to participate or to withdraw at any time without your current or future relations with Texas A&M University (or any related System affiliates) being affected.

Who will know about my participation in this research study?

This study is confidential and the records of this study will be kept private. No identifiers linking you to this study will be included in any sort of report that might be published. Research records will be stored securely and only Dr. Robin R. Murphy and Mr. Joshua Peschel will have access to the records.

If you choose to participate in this study, you will be video recorded with audio. Any audio/video recordings will be stored securely and only Dr. Robin R. Murphy and Mr. Joshua Peschel will have access to the recordings. Any recordings will be kept for 3-years and then erased.

Is there anything else I should consider?

The researchers can choose to end the experiment at any time.

Whom do I contact with questions about the research?

If you have questions regarding this study, you may contact Dr. Robin R. Murphy, (979) 845-2015, murphy@cse.tamu.edu or Mr. Joshua Peschel, (979) 324-0985, peschel@tamu.edu.

Whom do I contact about my rights as a research participant?

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979) 458-4067 or irb@tamu.edu.

Participation

Please be sure you have read the above information, asked questions and received answers to your satisfaction. If you would like to be in the study, please refer to and sign the consent form.

APPENDIX L

EXPERIMENTAL STUDY CONSENT FORM

IRB Version 01/24/12

Introduction

The purpose of this form is to provide you information that may affect your decision as to whether or not to participate in this research study. If you decide to participate in this study, this form will also be used to record your consent.

You have been asked to participate in a research project study that examines the individual performance of a human interacting with an unmanned aerial vehicle (UAV). The purpose of this study is to evaluate an Apple iPad® application we have developed that will allow you to view real-time video from a UAV and capture image of pre-determined objects. You were selected to be a possible participant because you have experience as a specialized emergency responder and/or are a roboticist who develops search and rescue robotics technology.

What will I be asked to do?

If you agree to participate in this study, you will be asked to 1) complete a pre-study background survey and short training meeting, 2) watch a video feed on an Apple iPad® or a laptop computer and interact with the UAV camera to capture images from the video of pre-determined objects when they become visible, and 3) complete a post-study survey. This study will take approximately 2-hours to complete.

Your participation will be video recorded with audio.

What are the risks involved in this study?

The risks associated with this study are minimal, and are not greater than the risks ordinarily encountered in daily life.

What are the possible benefits of this study?

The possible benefits of participation are that you will gain experience working with a UAV in a high-fidelity search and rescue exercise that uses cutting-edge robotics technology.

Do I have to participate?

No. Your participation is voluntary. You may decide not to participate or to withdraw at any time without your current or future relations with Texas A&M University (or any

related System affiliates) being affected.

Who will know about my participation in this research study?

This study is confidential and the records of this study will be kept private. No identifiers linking you to this study will be included in any sort of report that might be published. Research records will be stored securely and only Dr. Robin R. Murphy and Mr. Joshua Peschel will have access to the records.

If you choose to participate in this study, you will be video recorded with audio. Any audio/video recordings will be stored securely and only Dr. Robin R. Murphy and Mr. Joshua Peschel will have access to the recordings. Any recordings will be kept for 3-years and then erased.

Is there anything else I should consider?

The researchers can choose to end the experiment at any time.

Whom do I contact with questions about the research?

If you have questions regarding this study, you may contact Dr. Robin R. Murphy, (979) 845-2015, murphy@cse.tamu.edu or Mr. Joshua Peschel, (979) 324-0985, peschel@tamu.edu.

Whom do I contact about my rights as a research participant?

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979) 458-4067 or irb@tamu.edu.

Signature

Please be sure you have read the above information, asked questions and received answers to your satisfaction. You will be given a copy of the consent form for your records. By signing this document, you consent to participate in this study.

Signature of Participant: _____ Date: _____

Printed Name: _____

Signature of Person Obtaining Consent: _____ Date: _____

Printed Name: _____

APPENDIX M**EXPERIMENTAL STUDY PRE-ASSESSMENT**

Please answer the following survey questions. All information is confidential and will be used for research purposes only.

Question 1: What is your age?

- (a) Under 25-years
- (b) 25-years to 34-years
- (c) 35-years to 44-years
- (d) 45-years to 54-years
- (e) 55-years and older

Question 2: What is your gender?

- (a) Male
- (b) Female

Question 3: What is your current occupation? _____**Question 4: What is your ethnicity/race? _____****Question 5: Have you ever used a mobile touch-based device (e.g., Apple iPhone® or iPad®) before?**

- (a) Yes
- (b) No

Question 6: If you answered ‘Yes’ to Question 5, do you currently use any of the following mobile touch-based devices? If you answered ‘No’ to Question 5, please skip to Question 10.

- (a) Apple iPhone®
- (b) Apple iPad®
- (c) Android™ phone
- (d) Android™ tablet
- (e) Other touch-based phone or tablet, please specify: _____

Question 7: If you answered ‘Yes’ to Question 5, how long have you used mobile touch-based devices? If you answered ‘No’ to Question 5, please skip to Question 10.

- (a) 0 to 6-months
- (b) 6- to 12-months
- (c) More than 1-year
- (d) More than 2-years
- (e) More than 3-years

Question 8: If you answered ‘Yes’ to Question 5, how often do you use mobile touch-based devices? If you answered ‘No’ to Question 5, please skip to Question 10.

- (a) Continuously throughout every day
- (b) A few times per week
- (c) A few times per month
- (d) A few times per year

Question 9: If you answered ‘Yes’ to Question 5, in what context to you typically interact with mobile touch-based devices? If you answered ‘No’ to Question 5, please skip to Question 10. This question can have more than one answer.

- (a) I use it as my phone
- (b) I use it to play games
- (c) I use it to surf the Internet
- (d) I use it to check email
- (e) I do not own a device but I borrow from others

Question 10: Have you ever used a Tablet PC or other electronic pen-based device before?

- (a) Yes
- (b) No

Question 11: If you answered ‘Yes’ to Question 10, how long have you used a Tablet PC or other electronic pen-based devices? If you answered ‘No’ to Question 10, please skip to Question 14.

- (a) 0 to 6-months
- (b) 6- to 12-months
- (c) More than 1-year
- (d) More than 2-years
- (e) More than 3-years

Question 12: If you answered ‘Yes’ to Question 10, how often do you use a Tablet PC or other electronic pen-based devices? If you answered ‘No’ to Question 10, please skip to Question 14.

- (a) Continuously throughout every day
- (b) A few times per week
- (c) A few times per month
- (d) A few times per year

Question 13: If you answered ‘Yes’ to Question 10, in what context to you typically interact with a Tablet PC or other electronic pen-based devices? If you answered ‘No’ to Question 10, please skip to Question 14.

- (a) I use it as my primary computer
- (b) I use it to play games
- (c) I use it to surf the Internet
- (d) I use it to check email
- (e) I do not own a device but I borrow from others

Question 14: How often do you play video games?

- (a) Continuously throughout every day
- (b) A few times per week
- (c) A few times per month
- (d) A few times per year
- (e) I do not play video games

Question 15: If you do play video games, how often do you play first-person action games (e.g., Quake, HalfLife, etc.)?

- (a) Continuously throughout every day
- (b) A few times per week
- (c) A few times per month
- (d) A few times per year
- (e) I do not play first-person simulation games

Question 16: Have you ever interacted with a robot before?

- (a) Yes
- (b) No

Question 17: If you answered 'Yes' to Question 16, how often have you interacted with a robot before?

- (a) Once
- (b) Yearly
- (c) Monthly
- (d) Weekly
- (e) Daily

Question 18: Have you ever owned a robot before?

- (a) Yes
- (b) No

Question 19: If you answered 'Yes' to Question 18, please briefly describe the type(s) of robot(s) you have owned before.

Question 20: Have you ever flown RC helicopters or a plane?

- (a) Yes
- (b) No

Question 21: If you answered 'Yes' to Question 20, please briefly describe the type(s) of RC helicopter(s) and/or plane(s) you have flown before. If you answered 'No' to Question 20, please skip to Question 23.

Question 22: If you answered ‘Yes’ to Question 20, how would you rate your flying expertise? If you answered ‘No’ to Question 20, please skip to Question 23

- (a) Novice
- (b) Below Average Expertise
- (c) Average Expertise
- (d) Above Average Expertise
- (e) Expert

Question 23: Do you currently have a pilot’s license?

- (a) Yes
- (b) No

Question 24: Have you ever controlled a camera remotely before (e.g., on a robot or through the Internet)?

- (a) Yes
- (b) No

Question 25: If you answered ‘Yes’ to Question 24, please briefly describe the situation(s) in which you have controlled a camera remotely before.

Question 26: Have you ever participated in a search and rescue or accident/disaster response mission or exercise before?

- (a) Yes
- (b) No

Question 27: If you answered ‘Yes’ to Question 26, please briefly list and/or describe your role (function and command level; some examples may be: technical search team lead, transportation consulting reporting to DOT, etc.) in the situation(s) in which you have participated in a search and rescue or accident/disaster response mission before.

Question 28: Have you ever participated in a robot-assisted search and rescue or accident/disaster response mission or exercise before?

- (a) Yes
- (b) No

Question 29: If you answered ‘Yes’ to Question 28, please briefly list and/or describe your role (function and command level; some examples may be: technical search team lead, transportation consulting reporting to DOT, etc.) and the type of robot (e.g., air, ground, sea) in the situation(s) in which you have participated in a robot-assisted search and rescue or accident/disaster response mission before.

Question 30: Do you currently supervise one or more person(s) in a team or work environment?

- (a) Yes
- (b) No

Question 31: If you answered ‘Yes’ to Question 30, please briefly list and/or describe your role(s) (function and command level; some examples may be: technical search team lead, transportation consulting reporting to DOT, etc.) and the type of supervision(s) you provide.

Question 32: List below are information and/or technology methods that can be used for decision-making. Circle the best choice that reflects your use of the information and/or technology method for decision-making in your current job.

Verbal Reports (e.g., telling someone “the area is all clear”)

- (a) Never Use
- (b) Below Average Use
- (c) Average Use
- (d) Above Average Use
- (e) Always Use

Geographic Information on Paper Maps (e.g., topo maps)

- (a) Never Use
- (b) Below Average Use
- (c) Average Use
- (d) Above Average Use
- (e) Always Use

Geographic Information on an Electronic Device (e.g., Google maps)

- (a) Never Use
- (b) Below Average Use
- (c) Average Use
- (d) Above Average Use
- (e) Always Use

Digital Photographs and/or Video (e.g., digital cameras)

- (a) Never Use
- (b) Below Average Use
- (c) Average Use
- (d) Above Average Use
- (e) Always Use

Commercial or Custom Apps on a Mobile Electronic Device (e.g., Apple iPhone®, Android™, etc.)

- (a) Never Use
- (b) Below Average Use; Please Specify Apps: _____
- (c) Average Use; Please Specify Apps: _____
- (d) Above Average Use; Please Specify Apps: _____
- (e) Always Use; Please Specify Apps: _____

Question 33: List below are information and/or technology methods that can be used for decision-making. Circle the best choice that reflects your creation of the information and/or technology method for decision-making in your current job.

Verbal Reports (e.g., telling someone “the area is all clear”)

- (a) Never Create
- (b) Below Average Creation
- (c) Average Creation
- (d) Above Average Creation
- (e) Always Create

Geographic Information on Paper Maps (e.g., topo maps)

- (a) Never Create
- (b) Below Average Creation
- (c) Average Creation
- (d) Above Average Creation
- (e) Always Create

Geographic Information on an Electronic Device (e.g., Google maps)

- (a) Never Create
- (b) Below Average Creation
- (c) Average Creation
- (d) Above Average Creation
- (e) Always Create

Digital Photographs and/or Video (e.g., digital cameras)

- (a) Never Create
- (b) Below Average Creation
- (c) Average Creation
- (d) Above Average Creation
- (e) Always Create

Commercial or Custom Apps on a Mobile Electronic Device (e.g., Apple iPhone®,
Android™, etc.)

- (a) Never Create
- (b) Below Average Creation; Please Specify Apps: _____
- (c) Average Creation; Please Specify Apps: _____
- (d) Above Average Creation; Please Specify Apps: _____
- (e) Always Creation; Please Specify Apps: _____

Question 34: List below are information and/or technology methods that can be used for decision-making. If your job does not currently utilize one or more of the listed items, please circle which one(s) do you wish it did.

- (a) Verbal Reports
- (b) Geographic Information on Paper Maps
- (c) Geographic Information on Electronic Devices
- (d) Digital Photographs and/or Video
- (e) Commercial or Custom Apps on a Mobile Electronic Device
- (f) Other (please specify): _____

Question 35: On the following pages, there are phrases describing people's behaviors. Please use the rating scale below to describe how accurately each statement describes you. Describe yourself as you generally are now, not as you wish to be in the future. Describe yourself as you honestly see yourself, in relation to other people you know of the same sex as you are, and roughly your same age. So that you can describe yourself in an honest manner, your responses will be kept in absolute confidence. Please read each statement carefully, and then circle the number that corresponds to the number on the scale.

Response Options:

- 1: Very Inaccurate
- 2: Moderately Inaccurate
- 3: Neither Inaccurate nor Accurate
- 4: Moderately Accurate
- 5: Very Accurate

Try to surpass others' accomplishments.

1 2 3 4 5

Very Inaccurate

Very Accurate

Break my promises.

1 2 3 4 5

Very Inaccurate

Very Accurate

Try to outdo others.

1 2 3 4 5

Very Inaccurate

Very Accurate

Am afraid I will do the wrong thing.

1 2 3 4 5

Very Inaccurate

Very Accurate

Am quick to correct others.

1	2	3	4	5
Very Inaccurate				Very Accurate

Feel that I'm unable to deal with things.

1	2	3	4	5
Very Inaccurate				Very Accurate

Impose my will on others.

1	2	3	4	5
Very Inaccurate				Very Accurate

Avoid responsibilities.

1	2	3	4	5
Very Inaccurate				Very Accurate

Demand explanations from others.

1	2	3	4	5
Very Inaccurate				Very Accurate

Suspect hidden motives in others.

1	2	3	4	5
Very Inaccurate				Very Accurate

Want to control the conversation.

1	2	3	4	5
Very Inaccurate				Very Accurate

Feel that my life lacks direction.

1	2	3	4	5
Very Inaccurate				Very Accurate

Am not afraid of providing criticism.

1	2	3	4	5
Very Inaccurate				Very Accurate

Do not like art.

1	2	3	4	5
Very Inaccurate				Very Accurate

Challenge others' points of view.

1	2	3	4	5
Very Inaccurate				Very Accurate

Believe that too much tax money goes to support artists.

1	2	3	4	5
Very Inaccurate				Very Accurate

Lay down the law to others.

1	2	3	4	5
Very Inaccurate				Very Accurate

Look for hidden meanings in things.

1	2	3	4	5
Very Inaccurate				Very Accurate

Put people under pressure.

1	2	3	4	5
Very Inaccurate				Very Accurate

Become overwhelmed by events.

1	2	3	4	5
Very Inaccurate				Very Accurate

Hate to seem pushy.

1	2	3	4	5
Very Inaccurate				Very Accurate

Feel lucky most of the time.

1	2	3	4	5
Very Inaccurate				Very Accurate

Question 36: On the following pages, there are phrases describing people's behaviors. Please use the rating scale below to describe how accurately each statement describes you. Describe yourself as you generally are now, not as you wish to be in the future. Describe yourself as you honestly see yourself, in relation to other people you know of the same sex as you are, and roughly your same age. So that you can describe yourself in an honest manner, your responses will be kept in absolute confidence. Please read each statement carefully, and then circle the number that corresponds to the number on the scale.

Response Options:

- 1: Very Inaccurate
- 2: Moderately Inaccurate
- 3: Neither Inaccurate nor Accurate
- 4: Moderately Accurate
- 5: Very Accurate

Don't like to draw attention to myself.

1 2 3 4 5

Very Inaccurate

Very Accurate

Am comfortable in unfamiliar situations.

1 2 3 4 5

Very Inaccurate

Very Accurate

Keep in the background.

1 2 3 4 5

Very Inaccurate

Very Accurate

Feel at ease with people.

1 2 3 4 5

Very Inaccurate

Very Accurate

Dislike being the center of attention.

1 2 3 4 5

Very Inaccurate

Very Accurate

Am relaxed most of the time.

1 2 3 4 5

Very Inaccurate

Very Accurate

Don't talk a lot.

1 2 3 4 5

Very Inaccurate

Very Accurate

Love life.

1 2 3 4 5

Very Inaccurate

Very Accurate

Don't mind being the center of attention.

1 2 3 4 5

Very Inaccurate

Very Accurate

Feel comfortable with myself.

1	2	3	4	5
Very Inaccurate				Very Accurate

Take charge.

1	2	3	4	5
Very Inaccurate				Very Accurate

Tend to vote for conservative political candidates.

1	2	3	4	5
Very Inaccurate				Very Accurate

Want to be in charge.

1	2	3	4	5
Very Inaccurate				Very Accurate

Believe laws should be strictly enforced.

1	2	3	4	5
Very Inaccurate				Very Accurate

Am the life of the party.

1	2	3	4	5
Very Inaccurate				Very Accurate

Seldom complain.

1	2	3	4	5
Very Inaccurate				Very Accurate

Can talk others into doing things.

1	2	3	4	5
Very Inaccurate				Very Accurate

Get to work at once.

1	2	3	4	5
Very Inaccurate				Very Accurate

Seek to influence others.

1	2	3	4	5
Very Inaccurate				Very Accurate

Question 37: Please read each statement. Where there is a blank, decide what your normal or usual attitude, feeling, or behavior would be:

Response Options:

- A:** Rarely (less than 10% of the time)
B: Occasionally (about 30% of the time)
C: Sometimes (about half the time)
D: Frequently (about 70% of the time)
E: Usually (more than 90% of the time)

Of course, there are always unusual situations in which this would not be the case, but think of what you would do or feel in most normal situations.

Circle the letter that describes your usual attitude or behavior.

When faced with a problem I _____ try to forget it.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ need frequent encouragement from others for me to keep working at a difficult task.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ like jobs where I can make decisions and be responsible for my own work.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ change my opinion when someone I admire disagrees with me.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

If I want something I _____ work hard to get it.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ prefer to learn the facts about something from someone else rather than have to dig them out myself.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I will _____ accept jobs that require me to supervise others.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ have a hard time saying “no” when someone tries to sell me something I don’t want.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ like to have a say in any decisions made by any group I'm in.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ consider the different sides of an issue before making any decisions.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

What other people think _____ has a great influence on my behavior.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

Whenever something good happens to me I _____ feel it is because I've earned it.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ enjoy being in a position of leadership.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ need someone else to praise my work before I am satisfied with what I've done.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I am _____ sure enough of my opinions to try and influence others.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

When something is going to affect me I _____ learn as much about it as I can.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ decide to do things on the spur of the moment.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

For me, knowing I've done something well is _____ more important than being praised by someone else.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ let other people's demands keep me from doing things I want to do.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ let other people's demands keep me from doing things I want to do.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ stick to my opinions when someone disagrees with me.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ do what I feel like doing not what other people think I ought to do.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ get discouraged when doing something that takes a long time to achieve results.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

When part of a group I _____ prefer to let other people make all the decisions.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

When I have a problem I _____ follow the advice of friends or relatives.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ enjoy trying to do difficult tasks more than I enjoy trying to do easy tasks.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

I _____ prefer situations where I can depend on someone else's ability rather than just my own.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

Having someone important tell me I did a good job is _____ more important to me than feeling I've done a good job.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

When I'm involved in something I _____ try to find out all I can about what is going on even when someone else is in charge.

A	B	C	D	E
Very Rarely	Occasionally	Sometimes	Frequently	Usually

APPENDIX N**EXPERIMENTAL STUDY COMMAND PROTOCOLS**

In the case of the mirrored display (The Control Trial) participants should only use the following verbal commands to instruct the *Pilot*:

Camera Controls:

Tilt Camera Up
Tilt Camera Down
Zoom Camera In
Zoom Camera Out
Take Photo

Vehicle Controls:

Turn Left ___ Degrees
Turn Right ___ Degrees

In the case of the controllable display (The Experimental Trial) participants may use the following verbal commands to instruct the *Pilot*:

Camera Controls:

Tilt Camera Up
Tilt Camera Down
Zoom Camera In
Zoom Camera Out
Take Photo

Vehicle Controls:

Turn Left ___ Degrees
Turn Right ___ Degrees

In the experimental study, participants were instructed that the AirRobot® AR-100B camera controls on the Apple® iPad were defined by the gestures as shown in Figure N.1. Note that in the experimental study, participants could choose to have the zoom pinch controls reversed if it was more intuitive for them.

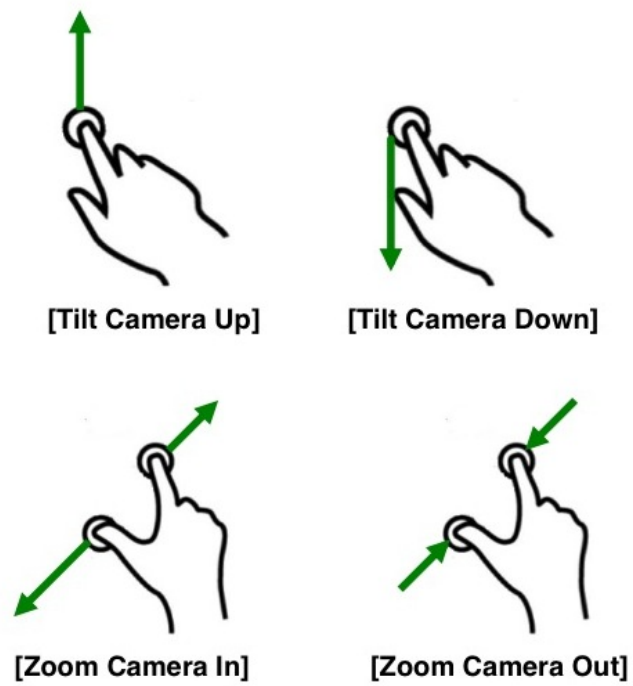


Fig. N.1. Gestures Used During the Experimental Study for Apple iPad® Control of the AirRobot® AR-100B Payload Camera (Courtesy of Center for Robot-Assisted Search and Rescue).

APPENDIX O

EXPERIMENTAL STUDY MISSION SCRIPT

Welcome the participants to the study. Introduce yourself and the other members of the research team. Obtain verbal confirmation from each participant that both the Information Sheet (Appendix K) has been received and read, and that the Consent Form (Appendix L) has been received, read, and signed.

In the case of the mirrored display (The Control Trial) say this:

You will be participating as part of an unmanned aerial system, which includes a human team and a micro unmanned aerial vehicle, for the purposes of investigating a simulated train derailment involving hazardous materials. Your team's mission is to fly a predetermined pattern over the accident scene to capture and interpret video that may aid other responders to deal with the accident.

Your role will be as the *Mission Specialist*. Your responsibilities are to watch the live video feed from the unmanned aerial vehicle camera on the *Mission Specialist* interface and verbally direct the *Pilot* to control the camera (tilt and zoom) and take photographs when an identified target becomes visible. During the mission you may refer to a quick reference sheet indicating commands you may give the *Pilot* for camera control. At various points in the mission, I will ask you one or more questions about a specific target that is being examined.

We will be recording the mission activities on video, therefore please speak clearly and loud enough to be recorded. We will also be monitoring your heart rate, so please do not interfere with or remove any of the monitoring equipment. If the equipment becomes uncomfortable at any time, please let me know and we will adjust it for you. If you have any questions about how to operate the *Mission Specialist* interface, I can answer those for you. However, I cannot answer any questions about the mission itself. Do you have any questions before we start?

In the case of the controllable display (The Experimental Trial) say this:

You will be participating as part of an unmanned aerial system, which includes a human team and a micro unmanned aerial vehicle, for the purposes of investigating a simulated train derailment involving hazardous materials. Your team's mission is to fly a predetermined pattern over the accident scene to capture and interpret video that may aid other responders to deal with the accident.

Your role will be as the *Mission Specialist*. Your responsibility is to watch the live video feed from the unmanned aerial vehicle camera, control the camera (tilt and zoom), and take pictures using the *Mission Specialist* interface when an identified target becomes visible. At various points in the mission, I will ask you one or more questions about a specific target that is being examined.

We will be recording the mission activities on video, therefore please speak clearly and loud enough to be recorded. We will also be monitoring your heart rate, so please do not interfere with or remove any of the monitoring equipment. If the equipment becomes uncomfortable at any time, please let me know and we will adjust it for you. If you have any questions about how to operate the *Mission Specialist* interface, I can answer those for you. However, I cannot answer any questions about the mission itself. Do you have any questions before we start?

When the participant finishes the mission, thank them for participating and direct them back to the main building.

APPENDIX P

EXPERIMENTAL STUDY SCRIPT FOR FLIGHT 1

If using the traditional approach, read the mirrored display mission script (Appendix O).

If using the dedicated approach, read the controllable display mission script (Appendix O).

Because every participant has to go through the same tasks and have the opportunity to see the same things in the same amount of time, we have to constrain how you would most likely use a UAV in practice or what different models of UAVs can do. We would be happy to talk with you about UAVs after the experiments.

For this flight, the pilot will go to three different waypoints. At each waypoint you will then answer a set of questions and get specific pictures. At each waypoint, the UAV will have to stay at the same altitude and cannot move its location (i.e., backwards or forwards, or side to side). However, you can tell the *Pilot* to turn the UAV turn left or right, make the camera zoom in and out, and make the camera turn up and down.

Your goal is to answer all the questions and get the pictures for all the waypoints within 10-minutes.

We will now begin Flight 1. You do not have to pay attention before we get to waypoint 1 or between waypoints.

[Waypoint 1: Looking at Front of Train; Altitude: 50-feet]:

We are now at Waypoint 1 (Figure P.1). We will now begin and remember to use:

If Traditional: specific verbal commands to direct the *Pilot*

If Dedicated: Apple® iPad interface and/or specific verbal commands to direct the *Pilot*

Question 1a: Yes or No, can you identify any derailed train cars?

Question 1b: Verbally indicate which train cars have been derailed.

Question 1c: Capture a photo of each derailed train car you indicated.

Question 2a: Yes or No, can you identify any product or material that has spilled from any of the derailed train cars?



Fig. P.1. Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 1 on Flight 1 (Courtesy of Center for Robot-Assisted Search and Rescue).

Question 2b: Verbally indicate which train cars have product or material spilling.

Question 2c: Capture a photo of each derailed train car with product or material spilling you indicated.

Now we are moving to Waypoint 2.

[Waypoint 2: Backed Up from Tanker Truck; Altitude: 50-feet]:

We are now at Waypoint 2 (Figure P.2). We will now begin and remember to use:

If Traditional: specific verbal commands to direct the *Pilot*

If Dedicated: Apple® iPad interface and/or specific verbal commands to direct the *Pilot*

Question 1a: Yes or No, can you identify the tanker truck?

Question 1b: Verbally indicate the current orientation of the tanker truck relative to the train.

Question 1c: Capture a photo of the tanker truck with the orientation you indicated.

Question 2a: Yes or No, can you identify any punctures or ruptures to the tanker truck?



Fig. P.2. Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 2 on Flight 1 (Courtesy of Center for Robot-Assisted Search and Rescue).

Question 2b: Verbally indicate how many punctures or ruptures you can identify.

Question 2c: Capture photos of each puncture or rupture you identified.

Now we are moving to Waypoint 3.

[Waypoint 3: Near Side of Black Train Engine; Altitude: 50-feet]

We are now at Waypoint 3 (Figure P.3). We will now begin and remember to use:

If Traditional: specific verbal commands to direct the *Pilot*

If Dedicated: Apple® iPad interface and/or specific verbal commands to direct the *Pilot*

Question 1a: Yes or No, can you identify the black train engine?

Question 1b: Yes or No, is there any fire or smoke coming from the black train engine.

Question 1c: Capture a photo of the black train engine.

Question 2a: Yes or No, can you identify the identification number on black train engine?

Question 2b: Verbally indicate the identification number on the black train engine.



Fig. P.3. Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 3 on Flight 1 (Courtesy of Center for Robot-Assisted Search and Rescue).

Question 2c: Capture a photo of the identification number on the black train engine you indicated.

We are now done with Flight 1.

APPENDIX Q

EXPERIMENTAL STUDY SCRIPT FOR FLIGHT 2

If using the traditional approach, read the mirrored display mission script (Appendix O).

If using the dedicated approach, read the controllable display mission script (Appendix O).

This will be a different set of three waypoints but your goal is same: to answer all the questions and get the pictures for all the waypoints within 10-minutes.

As before, you do not have to pay attention before we get to waypoint or between waypoints.

[Waypoint 1: On Top of Black Tanker Cars; Altitude: 50-feet]:



Fig. Q.1. Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 1 on Flight 2 (Courtesy of Center for Robot-Assisted Search and Rescue).

We are now at Waypoint 1 (Figure Q.1). We will now begin and remember to use:

If Traditional: specific verbal commands to direct the *Pilot*

If Dedicated: Apple® iPad interface and/or specific verbal commands to direct the *Pilot*

Question 1a: Yes or No, can you identify the black tanker cars?

Question 1b: Verbally indicate the current orientation of the black tanker cars relative to each other.

Question 1c: Capture a photo of the black tanker cars.

Question 2a: Yes or No, can you identify the identification number on topmost black tanker car?

Question 2b: Verbally indicate the identification number on the topmost black tanker car.

Question 2c: Capture a photo of the identification number on the topmost black tanker car you indicated.

Now we are moving to Waypoint 2.

[Waypoint 2: Overturned Gray Tanker Car; Altitude: 50-feet]:



Fig. Q.2. Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 2 on Flight 2 (Courtesy of Center for Robot-Assisted Search and Rescue).

We are now at Waypoint 2 (Figure Q.2). We will now begin and remember to use:

If Traditional: specific verbal commands to direct the *Pilot*

If Dedicated: Apple® iPad interface and/or specific verbal commands to direct the *Pilot*

Question 1a: Yes or No, can you identify the overturned gray tanker car?

Question 1b: Verbally indicate the current orientation of the overturned gray tanker car relative to the train track.

Question 1c: Capture a photo of the orientation of the overturned gray tanker car that you indicated.

Question 2a: Yes or No, can you identify any disconnected wheel carriages from the overturned gray tanker car?

Question 2b: Verbally indicate how the number of disconnected wheel carriages you can count.

Question 2c: Capture a photo of each disconnected wheel carriage you identified.

Now we are moving to Waypoint 3.

[Waypoint 3: Near Side of Gray Tanker Car; Altitude: 50-feet]



Fig. Q.3. Image Captured by the AirRobot® AR-100B Payload Camera Illustrating the View from Waypoint 3 on Flight 2 (Courtesy of Center for Robot-Assisted Search and Rescue).

We are now at Waypoint 3 (Figure Q.3). We will now begin and remember to use:

If Traditional: specific verbal commands to direct the *Pilot*

If Dedicated: Apple® iPad interface and/or specific verbal commands to direct the *Pilot*

Question 1a: Yes or No, can you identify any missing train track?

Question 1b: Indicate the location of the missing train track.

Question 1c: Capture a photo of the missing train track you indicated.

Question 2a: Yes or No, can you identify any train tracks nearby the track on which the derailment has occurred?

Question 2b: Indicate the location of the nearby train track relative to the train track on which the derailment has occurred.

Question 2c: Capture a photo of the nearby train track you indicated.

We are now done with Flight 2.

APPENDIX R**EXPERIMENTAL STUDY POST-ASSESSMENT 1**

Please answer the following survey questions for the mirrored display trial. All information is confidential and will be used for research purposes only.

Question 1: How confident did you feel in your ability to instruct the *Pilot* to accurately move the camera up and down?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 2: How confident did you feel in your ability to instruct the *Pilot* to accurately zoom the camera in and out?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 3: How confident did you feel in your ability to instruct the *Pilot* to accurately take pictures?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 4: How comfortable did you feel asking the *Pilot* to move the camera up and down?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 5: How comfortable did you feel asking the *Pilot* to zoom the camera in and out?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 6: How comfortable did you feel asking the *Pilot* to accurately take pictures?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 7: How confident did you feel in your individual ability to accurately instruct the *Pilot* to acquire photos of the targets?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 8: How comfortable did you individually feel instructing the *Pilot* to acquire photos of the targets?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 9: How confident did you feel in your team's ability to accurately acquire photos of the targets when instructing the *Pilot*?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 10: How comfortable did you feel in your team's ability to acquire photos of the targets when instructing the *Pilot*?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

APPENDIX S**EXPERIMENTAL STUDY POST-ASSESSMENT 2**

Please answer the following survey questions for the controllable display trial. All information is confidential and will be used for research purposes only.

Question 1: How confident did you feel in your ability to accurately move the camera up and down with the touch interface?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 2: How confident did you feel in your ability to accurately zoom the camera in and out with the touch interface?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 3: How confident did you feel in your ability to accurately take pictures with the touch interface?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 4: How comfortable did you feel with the gesture to move the camera up and down with the touch interface?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 5: How comfortable did you feel with the gesture to zoom the camera in and out with the touch interface?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 6: How comfortable did you feel with the gesture to take pictures with the touch interface?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 7: How confident did you feel in your individual ability to accurately acquire photos of the targets using the touch interface?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 8: How comfortable did you individually feel in using the touch interface to acquire photos of the targets?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

Question 9: How confident did you feel in your team's ability to accurately acquire photos of the targets when using the touch interface?

- (a) Not confident at all
- (b) Somewhat not confident
- (c) Neutral
- (d) Somewhat confident
- (e) Very confident

Question 10: How comfortable did you feel in your team's ability to acquire photos of the targets when using the touch interface?

- (a) Not comfortable at all
- (b) Somewhat not comfortable
- (c) Neutral
- (d) Somewhat comfortable
- (e) Very comfortable

APPENDIX T**EXPERIMENTAL STUDY POST-ASSESSMENT 3**

Please answer the following survey questions after both trials are complete. All information is confidential and will be used for research purposes only.

Question 1: Which method were you most confident in using to accurately move the camera up and down?

- (a) Move the camera up and down yourself
- (b) Asking the *Pilot* to move the camera up and down
- (c) Both (a) and (b)

Question 2: Which method were you most confident in using to accurately zoom the camera in and out?

- (a) Zoom the camera in and out yourself
- (b) Asking the *Pilot* to zoom the camera in and out
- (c) Both (a) and (b)

Question 3: Which method were you most confident in using to accurately take photos?

- (a) Take photos yourself
- (b) Asking the *Pilot* to take photos
- (c) Both (a) and (b)

Question 4: Which method were you most comfortable in using to accurately move the camera up and down?

- (a) Move the camera up and down yourself
- (b) Asking the *Pilot* to move the camera up and down
- (c) Both (a) and (b)

Question 5: Which method were you most comfortable in using to accurately zoom the camera in and out?

- (a) Zoom the camera in and out yourself
- (b) Asking the *Pilot* to zoom the camera in and out
- (c) Both (a) and (b)

Question 6: Which method were you most comfortable in using to accurately take photos?

- (a) Take photos yourself
- (b) Asking the *Pilot* to take photos
- (c) Both (a) and (b)

Question 7: Which method were you most confident in using to locate targets?

- (a) Watch the video and asking the *Pilot* to control the camera
- (b) Controlling the camera yourself
- (c) Both (a) and (b)

Question 8: Which method were you most comfortable in using to locate targets?

- (a) Watching the video and asking the *Pilot* to control the camera
- (b) Controlling the camera yourself
- (c) Both (a) and (b)

Question 9: Which method were you most confident in using for your team to accurately acquire photos of the targets?

- (a) Watching the video and asking the *Pilot* to control the camera and take photos
- (b) Controlling the camera and taking photos yourself
- (c) Both (a) and (b)

Question 10: Which method were you most comfortable in using for your team to accurately acquire photos of the targets?

- (a) Watching the video and asking the *Pilot* to control the camera and take photos
- (b) Controlling the camera and taking photos yourself
- (c) Both (a) and (b)

Question 11: Which method allowed you to individually perform the best to accurately acquire photos of the targets?

- (a) Watching the video and asking the *Pilot* to control the camera and take photos
- (b) Controlling the camera and taking photos yourself
- (c) Both (a) and (b)

Question 12: Which method allowed your team to perform the best to accurately acquire photos of the targets?

- (a) Watching the video and asking the *Pilot* to control the camera and take photos
- (b) Controlling the camera and taking photos yourself
- (c) Both (a) and (b)

Question 13: If a UAV was given to your organization as a tool, would you be responsible for maintaining the robot?

- (a) Yes
- (b) No

Question 14: If a UAV was given to your organization as a tool, would you be responsible for the robot in terms of planning?

- (a) Yes
- (b) No

Question 15: If a UAV was given to your organization as a tool, would you likely be the one to pilot the robot?

- (a) Yes
- (b) No

Question 16: If a UAV was given to your organization as a tool, would you expect to use the data from the robot?

- (a) Yes
- (b) No

Question 17: On the following pages, there are statements related to your feelings during the study. Please use the rating scale below to describe how accurately each statement describes you. Please read each statement carefully, and then circle the number that corresponds to the number on the scale.

Response Options:

- 1: Strongly Disagree
- 2: Moderately Disagree
- 3: Neither Agree nor Disagree
- 4: Moderately Agree
- 5: Strongly Agree

The robot's primary purpose was to help me.

1	2	3	4	5
Strongly Agree				Strongly Disagree

The robot's primary purpose was to help my team.

1	2	3	4	5
Strongly Agree				Strongly Disagree

The robot would only do things that were in my best interest.

1	2	3	4	5
Strongly Agree				Strongly Disagree

The robot was more loyal to me than the *Pilot*.

1	2	3	4	5
Strongly Agree				Strongly Disagree

The robot was on my side.

1	2	3	4	5
Strongly Agree				Strongly Disagree

I trusted the robot.

1	2	3	4	5
Strongly Agree				Strongly Disagree

The *Pilot's* primary purpose was to help me.

1	2	3	4	5
Strongly Agree				Strongly Disagree

The *Pilot's* primary purpose was to help my team.

1	2	3	4	5
Strongly Agree				Strongly Disagree

The *Pilot* would only do things that were in my best interest.

1	2	3	4	5
Strongly Agree				Strongly Disagree

The *Pilot* was more loyal to me than the robot.

1	2	3	4	5
Strongly Agree				Strongly Disagree

I trusted the Apple iPad® interface.

1

2

3

4

5

Strongly Agree

Strongly Disagree

Question 18: Are there any feature changes or feature additions to the controllable interface that you would like to see?

Question 19: Do you have any other comments about this experiment?

VITA

Joshua Michael Peschel received a B.S. in biological systems engineering and a M.S. in biological & agricultural engineering in 2001 and 2004, respectively, from Texas A&M University. He began working with Professor Robin Murphy in the Department of Computer Science and Engineering at Texas A&M University in May 2010. Upon completion of his dissertation research in June 2012, Joshua joined the faculty in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign as a Research Assistant Professor.

Joshua may be reached at the Department of Civil and Environmental Engineering, 1114 Newmark Civil Engineering Laboratory, 205 North Matthews Avenue, Urbana, Illinois 61801-2352. His email is peschel@illinois.edu.