International Journal of Social Robotics
https://doi.org/10.1007/s12369-022-00872-3

Design and Field Evaluation of a Mission Specialist Interface for Small Unmanned Aerial Systems

Joshua M. Peschel[1] · Brittany A. Duncan[2] · Robin R. Murphy[3]

Accepted: 4 January 2022

Abstract

This article describes a small unmanned aerial system (sUAS) interface that allows untrained responders acting in a *Mission Specialist* role to effectively coordinate with a *Pilot* and directly control the UAS payload. Currently, responders view the same interface as the *Pilot* and give verbal directions for navigation and payload control. Field experiments with 26 experts in chemical, biological, radiological and nuclear response evaluated two interfaces for a chemical train derailment incident staged at Disaster City®. Responder participants had their own role-specific tablet display: one interface passively filtered *Pilot*-only artifacts from the payload camera video feed; the second interface added responder-specific indicators and information and allowed the participants to actively control the payload pan, tilt, and zoom and to take pictures. A majority of responders reported greater role empowerment for similar tasks using the responder-specific interface. This article demonstrates that a responder-specific interface is preferred by untrained responders instead of viewing the same interface as the *Pilot* in sUAS.

Keywords Tablet interface · Human robot interaction · UAV

1 Introduction

This paper presents the human-robot interaction (HRI) field investigation of a *Mission Specialist* interface for small unmanned aerial systems (sUAS) in the CBRN (chemical, biological, radiological, nuclear) domain. The small category of UAS are used in civilian-supported CBRN operations such as fire and rescue [1], law enforcement [2], and civil engineering [3]; further, sUAS are widely used in military-supported CBRN operations [4–6]. Current legislative trends for UAS integration into the national airspace suggest that sUAS are in high demand for these domains and will become widely available much faster than any other category of UAS [7].

All UAS involve a human team with clearly defined roles [8]. This work focuses on the *Mission Specialist*, one of three human team member roles (in addition to *Flight Director* and *Pilot*) first identified in [9] and summarized in Sect. 2.2.1. The *Mission Specialist* role is uniquely responsible for operating the unmanned aerial vehicle (UAV) payload yet current human-robot interface technology only permits duplicate or shared visualization with, and passive interaction through, the *Pilot* role [9] (Fig. 1). Understanding how a *Mission Specialist* role can interface with a UAV is critical for investigating HRI in sUAS, reducing the human-robot crewing ratio, and improving individual human role and team performance. This investigation provides a HRI study for a *Mission Specialist* interface with 26 expert CBRN responders. Field experiments for a chemical train derailment incident staged at Disaster City® compared two interface conditions: (i) only viewing a *Pilot*-artifacts-filtered, shared display and verbally directing the *Pilot* to control the UAV payload camera, and (ii) a role-based interface with responder-specific indicators and information, allowing responders full active control of camera payload.

The remainder of the article is organized as follows. Section 2 serves as a review of research literature for factors

✉ Joshua M. Peschel
peschel@iastate.edu

Brittany A. Duncan
bduncan@unl.edu

Robin R. Murphy
robin.r.murphy@tamu.edu

1 Agricultural and Biosystems Engineering, Iowa State University, 605 Bissell Road, Ames, IA 50011, USA

2 Computer Science and Engineering, University of Nebraska-Lincoln, 291 Schorr Center, Lincoln, NE 68588, USA

3 Computer Science and Engineering, Texas A&M University, 333 H.R. Bright Building, 77843 College Station, USA

Published online: 06 May 2022

Fig. 1 A sUAS *Mission Specialist* (far right) Passively Shares an Air-Robot® AR100-B 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)

associated with *Mission Specialist* HRI in sUAS. An initial implementation of a *Mission Specialist* interface with observations from an exploratory field study are also summarized in this section. In Sect. 3, the theoretical approach for this work is given where a Shared Roles Model for sUAS is formulated that includes two human team roles (*Pilot* and *Mission Specialist*). Refinements to the *Mission Specialist* interface from the exploratory study observations are also discussed. Sections 4 and 5 present the details for the experimental field study and associated findings, respectively. Finally, Sect. 6 presents the conclusions and future directions for this work. The work is expected to: (i) provide a new tool for HRI practitioners and researchers to investigate human-robot team performance in sUAS, (ii) serve as a reference document for unmanned system designers and developers, and (iii) contribute to a better understanding of vulnerabilities in HRI with sUAS.

2 Related Work

This section presents background material for understanding the HRI of a *Mission Specialist* role and interface for sUAS. 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 summary of *Mission Specialist* human-machine interaction (HMI) findings for sUAS is given. Finally, observations from an exploratory field study involving an initial implementation of the *Mission Specialist* interface are described.

2.1 Human-Robot Team Models for Small UAS

Several frameworks exist for collaboration modeling in human-robot teams [10]. For the case of sUAS, the Shared Roles Model (developed from Social Role Theory and described within the context of a Joint Cognitive System) provides a suitable framework for human-robot team interaction as it was based on empirical unmanned systems studies [11].

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 [12], 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 [11].

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 the premise 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 [11].

In Murphy and Burke [11], 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*) (Fig. 2). 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

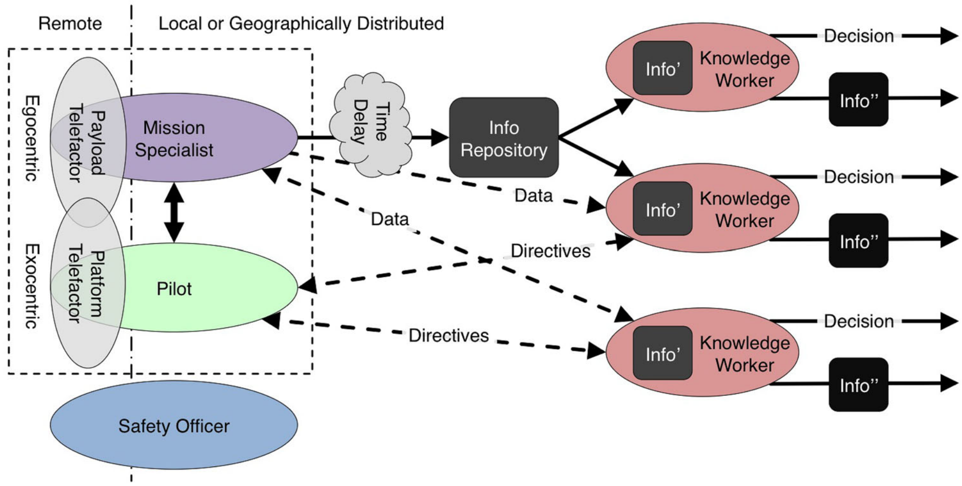

Fig. 2 Graphical Illustration of the Shared Roles Model for a Generic Unmanned System. Human Team Roles that May be Co-Located or Geographically Distributed are: *Mission Specialist*, *Pilot*, and *Safety Officer*. The *Pilot* maintains a Primarily Exocentric View of the UAV (Platform Telefactor) and the *Mission Specialist* has Primarily an Egocentric View (Payload Telefactor). Verbal Communication Between the *Pilot* and *Mission Specialist* Occurs, as Well as the Transfer of Data and Directives Between Both of These Roles and *Knowledge Workers* (From Murphy and Burke [11])

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.

2.2 HMI Technology for Small UAS

Peschel and Murphy [9] surveyed the human team roles and HMI currently used on 10 micro and small UAS human-robot teams. Three human team role trends were identified (*Flight Director*, *Pilot*, and *Mission Specialist*). Findings from [9] suggested that a *Mission Specialist* role requires a small, mobile, and visual interface that is dedicated and software-based.

2.2.1 Small UAS Human Team Roles

Human team member roles identified in [9] fall into one of three role categories: *Flight Director*, *Pilot*, and *Mission Specialist*. These three role labels represented a synthesis from the literature and were given to describe role function rather than rigid role titles within a UAS.

Flight Director was the role responsible for supervisory planning, coordination, and control of operations critical to mission success, especially for a sUAS human-robot team; across the sUAS field studies literature, one or more human team members were found to be responsible for directing the mission.

Pilot was the role responsible for operating the UAV and was common to all sUAS human-robot teams; however, the degree to which one or more individuals were solely responsible for flight control activity varied and navigation responsibilities were also included as a role responsibility and thus combined with the main function of piloting the UAV.

Mission Specialist was the role responsible for UAV payload sensor control and data acquisition; sUAS operations allow a human-robot team to insert themselves remotely for visual investigation and recording and a role solely responsible for the payload was a commonly identified role.

2.2.2 Small UAS Human-Machine Interaction

Three HMI findings were given in [9] that suggested current *Mission Specialist* performance in sUAS may be sub-optimal due to the sharing of a single *Pilot*-oriented interface or a reuse of the *Pilot* interface.

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. Small handheld controllers that could be carried and handled by one individual were the most common form of interaction device. Interactive feedback to the *Mission Specialist* was visual and took the form of small video displays, graphical menus, and real-time video.

Across the sUAS 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 sUAS in the literature had a dedicated *Mission Specialist* interface. Given that the *Mission Specialist* is a unique human team role, a distinct or different modality of HMI technology from that of the *Pilot* would be expected; therefore, existing interfaces, in general, do not support the functionality of the *Mission Specialist* role.

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 of the ten surveyed sUAS. The findings in [9] suggested that there is a heavily reliance on hardware-oriented interaction by current *Mission Specialists*. Current HMI for the *Pilot*-oriented interfaces could be limiting the software capabilities that may improve *Mission Specialist* performance in sUAS missions.

2.3 Exploratory Study

This section summarizes the overview, salient observations, and interface refinement recommendations for an exploratory field study of the *Mission Specialist* interface that determined a *Mission Specialist* preferred coordination with the *Pilot* versus only controlling the payload camera and capturing images themselves [16]. The exploratory study consisted of 16 CBRN responders each participating in two different sUAS mission trials to visually evaluate and capture images of a simulated train derailment involving hazardous materials. The most significant observations from the exploratory study indicated: (i) more role-specific information should appear in the *Mission Specialist* interface, and (ii) a person acting in the *Mission Specialist* role preferred coordination with the *Pilot*.

2.3.1 Exploratory Study Overview

The purpose of the exploratory study in [16] was to field test a *Mission Specialist*-controlled interface (Fig. 4) versus the *Mission Specialist* only passively viewing their own display and instructing the *Pilot* for payload camera control and image capture. The exploratory study took place at the Disaster City® facility located on the campus of Texas A&M University. The context of the sUAS missions was a simulated train derailment involving hazardous materials. A DraganFlyer™ X6 UAV was used in the exploratory study. The human acting in the *Pilot* role for the exploratory study had a significant number of hours flying small UAVs and was qualified as a corporate trainer for the DraganFlyer platforms. A second individual with a private pilot certificate was on-site to ensure compliance with FAA regulations; neither were researchers for the study or dedicated subject matter experts for specialized emergency response.

A 16 participant mixed-model study design was developed from the HRI study guidelines in [17]. Each participant received interface instructions and 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). The maximum duration of the flights were limited to 7-min 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 was randomized to counterbalance the study.

During condition 1, half of the participants passively viewed their own display (mirrored 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 control the camera and capture images (Fig. 4). 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 payload camera cannot turn left or right.

2.3.2 Exploratory Study Results and Observations

An analysis of the exploratory study results for the *Mission Specialist* interface resulted in two key observations: (i) visual feedback confusion was experienced using both interfaces, and (ii) more positive role empowerment (confidence and comfort) was reported when the *Mission Specialist* only passively viewed their own display and instructed the *Pilot*. These observations suggested that a *Mission Specialist* preferred coordination with the *Pilot* versus only controlling the payload camera and capturing images themselves [16].

Observation 1: 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 suggested 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 would be especially important if the *Mission Specialist* is a member of an *ad hoc*

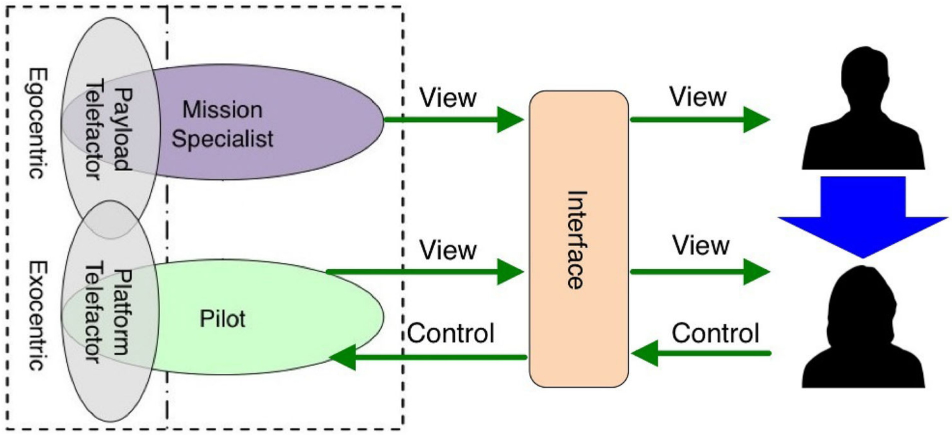

Fig. 3 Interface Formulation of the the Shared Roles Model for sUAS that Focuses Only the the *Pilot* and *Mission Specialist* Roles and Represents the State of the Practice Where the *Mission Specialist* is a Passive Viewer of the *Pilot* Interface. The Blue Arrow Indicates Verbal Communication from the Viewing-Only *Mission Specialist* (Top) to the *Pilot* (Bottom), Who is Solely Responsibe for Payload Camera Control and Image Capture. The *Knowledge Worker* and *Safety Officer* (*Flight Director*) Roles are Excluded to Simplify Focus Toward the *Mission Specialist* (Formulated from Murphy and Burke [11])

human-robot team and does not have training similar to that of the *Pilot*.

Observation 2: Participants reported more positive role empowerment when passively viewing a display and instructing the Pilot to control the payload camera and capture images. Role empowerment was reported in a post-assessment survey as confidence and comfort in the ability to execute tasks with each interface. Based on the exploratory study conditions, when using the *Mission Specialist* interface, participants were not allowed to ask the *Pilot* to control the payload camera and capture images. The lower reported role empowerment suggested that a *Mission Specialist* preferred to verbally coordinate with the *Pilot* versus directly controlling the payload camera and capturing images.

Supporting Observation 2 was mixed-model design for role empowerment 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 greater role empowerment regardless of mission trial when using the passive approach (M = 4.53, SD = 0.80) than they did using the dedicated *Mission Specialist* interface (M = 3.56, SD = 1.07) (M = mean, SD = standard deviation). On mission trial 1 when participants used the passive approach, greater role empowerment was reported (M = 4.33, SD = 0.96) than when using the dedicated *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 dedicated *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. The reader should see [16] for more in-depth details about the Exploratory Study.

3 Approach

This section provides the theoretical approach for a *Mission Specialist* interface in sUAS. A formulation of the Shared Roles Model is presented that includes two formal human team roles: *Pilot* and *Mission Specialist* (a *Flight Director (Safety Officer)* was present in the experimental study for proper operational procedure, but the role was not evaluated in this work). Recommended refinements to the *Mission Specialist* interface implemented in [16] are discussed that

Fig. 4 Initial Implementation of the *Mission Specialist* Interface on an Apple® iPad Used in the Exploratory Study by Peschel and Murphy [16]. A Captured Image of the Simulated Train Derailment is Shown in the Video Display Window. 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 Refined Implementation of the *Mission Specialist* Interface on an Apple® iPad Used in the Experimental Study. A Captured Image of the Simulated Train Derailment is Shown in the Video Display Window. The *Mission Specialist* Controls the Payload Camera and Captures Images in the Same Manner as the Initial Implementation in Peschel and Murphy [16]. Role-Specific Information Was Added that Included an Overview Map with UAV Position and Heading, a Digital Compass, and Payload Camera Tilt and Zoom Indicators (Courtesy of Center for Robot-Assisted Search and Rescue)

included role-specific information for UAV position and heading, as well as payload camera tilt and zoom indicators.

3.1 Shared Roles Model for Small UAS

To formulate the Shared Roles Model for sUAS, the *Knowledge Worker* and *Flight Director (Safety Officer)* roles are excluded in order to simplify focus toward the *Mission Specialist* (Fig. 3). Formal role labels in the model are defined as in Sect. 2.1.2: *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 small UAV. Figure 3 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.

3.2 Mission Specialist Interface Refinements

Based on the lack of adequate visual feedback observed during the exploratory field study, the *Mission Specialist* interface was refined to include role-specific information that included an overview map with real-time UAV position and heading, a digital compass, and payload camera tilt and zoom indicators (Fig. 5). The *Mission Specialist* controls the payload camera and captures images in the identical manner as the initial implementation described in [16]. The addition of the role-specific information to the interface effectively focused the visual common ground for the *Mission Specialist*.

With the refinements to the *Mission Specialist* interface resulting in a third version (or third state of the Shared Roles Model), it is appropriate to consider more precise terminology to define the method of interaction which can also be visualized and evaluated with the Shared Roles Model (Fig. 6). 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 (Fig. 6a). The *Mission Specialist* interface in the exploratory study is considered to be active-coordinated, filtered (Fig. 6b) since it permits only direct control of the payload camera and little verbal communication with the *Pilot*. The role-specific 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 (Fig. 6c). These more precise interface descriptions (passive-, active-, and dual-coordinated) will be used throughout the remainder of this paper.

4 Experiments

This section presents the experimental design, research hypotheses, and results for two *Mission Specialist* interface

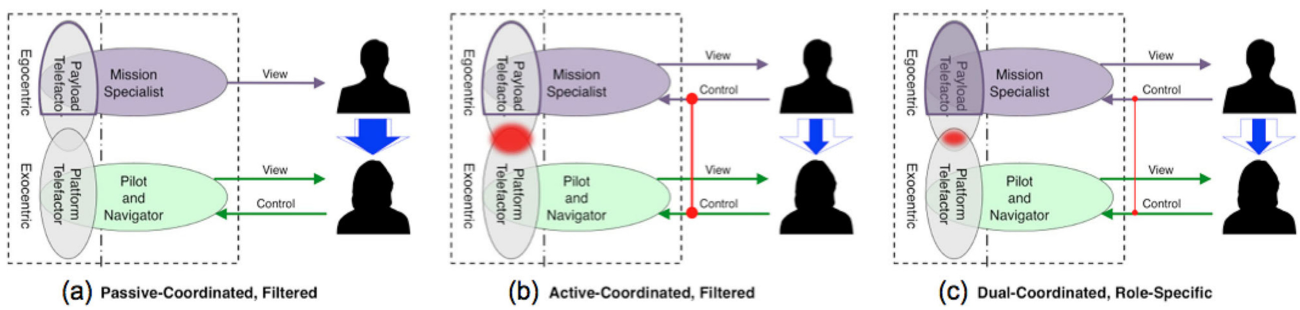

Fig. 6 Shared Roles Model Representations of the *Mission Specialist* Interface Versions. **a** The Passive-Coordinated, Filtered Interface Permits Only Passive Viewing of the Filtered *Pilot* Display and Verbal Direction of the *Pilot*. **b** The Active-Coordinated, Filtered Interface Permits Only Direct 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)

conditions (passive-coordinated, filtered and dual-coordinated, role-specific) to determine which interface increased *Mission Specialist* performance. Specific details regarding tasks, survey questions, etc. can be found in [8]. The experiment included 10 CBRN responders visually evaluating and capturing images of a simulated train derailment involving hazardous materials. Two research hypotheses were posed to determine which interface condition increased performance: (i) role empowerment (confidence, comfort, and perceived best individual and team performance), and (ii) task completion time (object identification, evaluation, image capture). Results showed that a *Mission Specialist* using the dual-coordinated, role-specific interface reported greater role empowerment while completing similar tasks in a similar amount of time as when using the passive-coordinated, filtered interface.

4.1 Design

A 10 participant complete 2 factorial mixed model design with within-subject factor interaction type (mirrored display vs. mission specialist display) and between-subject factor environment (flight environment 1 vs. flight environment 2) 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 up to a 5-min training flight to demonstrate understanding of the interface inputs prior to each experimental interface condition. The average time for demonstrated interface competence was 3-min. Two different UAV flights were made, one per mission trial, with each flight having three pre-defined stationary waypoints (Fig. 7); participants completed activities and answered questions at each waypoint, consisting of object identification, evaluation, and capturing images. The tasks and questions asked of the participants were carefully developed in conjunction with specialized emergency responders from the CBRN domain to reflect the most likely field conditions, activities, and needed information for which a small UAS and Mission Specialist interface would be used. The maximum duration of the flights were limited to 10-min 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. The human acting in the *Pilot* role for the experimental study held a private pilot certificate and had a significant number of hours flying the AirRobot® platform. This person was not a researcher for the study nor a dedicated subject matter expert for specialized emergency response.

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 1 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 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

Fig. 7 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)

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.

During interface 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 of the participants used the dual-coordinated, role-specific interface to control the camera and capture images (Fig. 5). 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 interface condition 2 used the interface they did not have in interface condition 1. Participants were fully counterbalanced in presentation order of flight environment and interface conditions, resulting in four experimental conditions.

4.2 Hypotheses

Two research hypotheses were developed from the findings of a comprehensive literature survey of existing *Mission Specialist* interfaces in UAS [9] and the exploratory field study observations for an active-coordinated, filtered *Mission Specialist* interface in [16].

Research Hypothesis 1: A Mission Specialist using a dual-coordinated, role-specific interface will report 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*.

Research Hypothesis 2: A Mission Specialist using a dual-coordinated, role-specific interface will complete tasks 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*.

4.3 Data Analyses and Results

Two analyses were performed on the data collected during the experimental field study: (i) role empowerment (confidence, comfort, perceived best individual and team performance) and (ii) task completion time (object identification, evaluation, image capture). Results showed that a *Mission Specialist* using the dual-coordinated, role-specific interface reported greater role empowerment while completing similar tasks in a similar amount of time as when using the passive-coordinated, filtered interface.

4.3.1 Role Empowerment Results

Summative post-assessment survey results for role empowerment (confidence, comfort, perceived best individual and team performance) indicated that a *Mission Specialist* reported greater role empowerment when using a dual-coordinated, role-specific interface. Results were obtained from three separate post-assessment survey instruments - one given after each condition was completed by a participant, as well as a final survey given at the completion of both conditions. The first two surveys were based on a 5-point Likert scale; the final survey asked the participant to choose one or the other condition (or both) as their interface condition preference (see Supplemental Material). The final survey allowed for the determination of participant perception for confidence, comfort, and perceived best individual and team performance between interface conditions. The questions were different between each of the three different post-assessments, and were randomized when administered, to avoid order effects. The percentages of participant responses for confidence and comfort are summarized in Table 1.

Ninety percent of participants reported the dual-coordinated, role-specific interface gave them the most confidence and comfort in their role as *Mission Specialist* for capturing images. For locating objects with the payload camera, 80-percent reported the most confidence in the dual-coordinated, role-specific interface. The percentage reporting the most comfort with the same interface dropped to 60-percent. Every participant asked the *Pilot* at least once to tilt or zoom the camera during the dual-coordinated, role-specific interface condition, while at the same time trying to complete the same operation themselves. Equal percentages were reported for confidence and comfort in payload camera tilt and zoom.

Participants were additionally asked which interface gave them the best individual and team performance. Sixty percent of participants reported use of the dual-coordinated, role-specific interface resulted in the best outcome for themselves as individuals, and separately, the best outcome for their team. Based on the results for confidence, comfort, and perceived best individual and team performance, a *Mission Specialist* using the dual-coordinated, role-specific interface reported greater role empowerment than when using the passive-coordinated, filtered interface and research hypothesis 1 was supported (Sect. 4.2).

4.3.2 Task Completion Time Results

An analysis of task completion time (object identification, evaluation, image capture) indicated that a *Mission Specialist* completed similar tasks in a similar amount of time using both interfaces. Results for the three categories of task completion time are shown in Table 2.

Task completion time for each of the three task completion categories (object identification, evaluation, image capture) was measured as the elapsed time between the question posed by the experimenter and the corresponding response by a participant. For object identification tasks, participant responses after locating an object with the payload camera were verbal and typically of the form *yes* or *no*. Evaluation task responses reflected the determination of information associated with located objects; participant responses for evaluation tasks were also verbal (e.g., *I count two disconnected wheel carriages*). Image capture task time was determined when a participant pressed the Capture Image button or instructed the *Pilot* to take a photo. Images were examined afterwards to verify the presence of objects that were indicated to be photographed. Every participant utilized the full 10-min allocated in each of the two flights.

Sauro and Lewis [18] have shown that the geometric mean (GM) is the best population center estimator to report for usability time studies involving less than 26 participants; this paper follows that recommendation for reporting and also includes the geometric standard deviation (GSD). The task completion time data for each category were determined to follow a log-normal distribution and were log transformed and evaluated for equivalence of means using Welch's t-test. Object identification task completion time was not statistically significantly different between the passive-coordinated, filtered interface (GM = 5.8, GSD = 4.8) and the dual-coordinated, role-specific interface (GM = 3.3, GSD = 5.7); $t(101) = 1.68$, $p = 0.096$. Evaluation task completion time was not statistically significantly different between the passive-coordinated, filtered interface (GM = 6.7, GSD = 3.1) and the dual-coordinated, role-specific interface (GM = 4.8, GSD = 4.3); $t(86) = 1.30$, $p = 0.197$. Image capture task completion time was not statistically significantly different between the passive-coordinated, filtered interface (GM = 6.7, GSD = 4.1) and the dual-coordinated, role-specific interface (GM = 5.6, GSD = 6.4); $t(82) = 0.26$, $p = 0.794$.

As shown in Table 2, on average, the dual-coordinated, role-specific interface resulted in numerically faster task completion time in each category; however, there was also a large variance observed which was the likely cause for the completion time means between interface conditions being not statistically significantly different.

5 Findings

Analyses of experimental data from a *Mission Specialist* using a dual-coordinated, role-specific interface versus a passive-coordinated, filtered interface resulted in three findings: i) greater role empowerment (confidence, comfort, perceived best individual and team performance) is experienced, ii) a *Mission Specialist* completes tasks in a similar amount of time, and iii) a *Mission Specialist* with command-level experience prefers shared control of the payload camera while non-commanders prefer only to ask the *Pilot*. The last finding suggests that the work experience of a *Mission Specialist* will influence the preferred method of HRI for sUAS operations.

Finding 1: Greater role empowerment is experienced by a Mission Specialist when using a dual-coordinated, role-specific interface. As seen in Table 1, 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

Table 1 Reported preference percentages for mission specialist role empowerment between interface conditions

Role empowerment category	Most confidence		Most comfort	
	Passive-coordinated, Filtered interface [percentage] n = 10	Dual-coordinated, Role-specific interface [percentage] n = 10	Passive-coordinated, Filtered interface [percentage] n = 10	Dual-coordinated, Role-specific interface [percentage] n = 10
Capturing images	10	90	10	90
Locating objects	20	80	40	60
Tilting the payload camera	50	50	50	50
Zooming the payload camera	50	50	50	50

Table 2 Statistical results for mission specialist task completion time [in Sec] between interface conditions[1]

Completion task category	Passive-coordinated, Filtered interface time [sec]	Dual-coordinated, Role-specific interface time [sec]	Time Difference [sec]	*p*-value
Object Identification	5.8	3.3	2.5	0.096
Evaluation	6.7	4.8	1.9	0.197
Image Capture	6.7	5.6	1.1	0.794

1 Geometric mean is reported as per [18]

(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, either by themselves or with assistance from the *Pilot*.

Finding 2: Similar tasks are completed by a Mission Specialist in a similar amount of time regardless of interface type. Each of the three task categories a *Mission Specialist* completed (object identification, evaluate, image capture) were determined to take a similar amount of time, if the *Mission Specialist* had direct control of the payload camera versus was only able to instruct the *Pilot* for payload camera control. The numeric results shown in Table 2 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. The largest task completion time result difference was for object identification, which 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. The most similar task completion time result was for capturing images. All participants 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.

Finding 3: Command-level experience of the Mission Specialist affects payload camera control preference. A *Mission Specialist* having command-level experience (e.g., Fire and Rescue Captain, EMS Team Leader) reported the most 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 their highest role empowerment resulted from only instructing the *Pilot* for payload camera control and image capture. This *Commander Effect* was determined through a correlation analysis 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 3).

Table 3 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

6 Conclusions

This work determined that a *Mission Specialist* in a sUAS 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 specialized responders from the CBRN domain showed that a *Mission Specialist* using the dual-coordinated, role-specific interface reported greater role empowerment while completing similar tasks in a similar amount of time as when using the passive-coordinated, filtered interface. The most significant finding was that the work experience of a *Mission Specialist* will influence the preferred interface for HRI in sUAS operations. The dual-coordinated, role-specific interface is the most appropriate interface for a *Mission Specialist*, regardless of work experience, as it permits both direct control of the payload camera and passive-coordination with the *Pilot*.

Greater individual confidence, comfort, and perceived best individual and team performance were reported by a *Mission Specialist* using a role-specific, shared visual common ground interface that permits verbal coordination with the *Pilot*. Role empowerment is key because greater self-efficacy (the idea that one is capable of performing in a certain manner or attaining certain goals) tends to directly correlate with better individual performance. This is especially important for *ad hoc* sUAS teams where specialized emergency responders acting in the role of *Mission Specialist* will likely not have regular training and exposure to small UAV technology. An additional consequence of greater role empowerment is that the adoption rate of small UAV technology by CBRN-related response agencies may increase as currently many do not utilize sUAS.

The elapsed time for a *Mission Specialist* to complete similar tasks either themselves and coordinated with the *Pilot*, or only asking the *Pilot*, was not found to be significantly different. This means that a *Mission Specialist* will perform as well having their own interface as they would with the current state of the practice, which is either sharing a display or passively viewing and only instructing the *Pilot* for camera control and image capture. The dual-coordinated, role-specific interface is a new tool that can be used by HRI practitioners and researchers to further study the *Mission Specialist* role and sUAS team performance and process. Further, the interface is an open-source software package that could be adopted by designers and developers of commercial small UAV technology to improve the HRI experience for a *Mission Specialist*.

The level of command experience that a *Mission Specialist* has affects their HRI in sUAS. Commanders want to share control of the payload camera with the *Pilot*. Non-commanders would rather ask the *Pilot* to control the payload camera and capture images. The dual-coordinated, role-specific interface eliminates this problem by accommodating both preferences; however, a more important consequence is that in either case, the *Mission Specialist* relied on the *Pilot* role. This is important for two reasons: (i) the potential increase in workload experienced by the *Pilot*, and (ii) the *Mission Specialist* wants a human in the *Pilot* role. This work did not address the *Pilot* due to limited availability of personnel trained to fly the UAV; however, the *Pilot* role should be investigated to better understand overall sUAS performance and process. That the *Mission Specialist* wanted a separate *Pilot* role has consequences for researchers attempting to automate the role (e.g., the robot or a software agent serving in the *Pilot* role). Unless the human-human interaction that a human *Pilot* provides could be reproduced in an autonomous agent, it is expected that a *Mission Specialist* would not perform similarly to the observed results.

This research suggests that more work is needed to better understand sUAS team performance and process, particularly as it relates to the *Pilot* role. More complete, long-term mission scenarios are recommended to evaluate individual and joint situation awareness. In particular, it is not known what task and/or environmental factors caused control of the payload camera to be ceded from the *Mission Specialist* to the *Pilot*, even when the *Mission Specialist* preferred to have control. Understanding these issues in the context of HRI are important as sUAS are integrated into CBRN-related operations and the national airspace.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12369-022-00872-3.

Acknowledgements This material is based upon work supported by the National Science Foundation under Grants: IIS-1143713, EAGER: Shared Visual Common Ground in Human-Robot Interaction for Small Unmanned Aerial Systems and 1925262, NRI: INT: COLLAB: Leveraging Environmental Monitoring UAS in Rainforests.

Data Availibility The data sets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest.

References

1. *Darley Stinger drone helicopter gives firefighters 'eye in the sky'*. FireRescue1. (2011, August 18). Retrieved April 28, 2022, from https://www.firerescue1.com/fireproducts/vehicles/articles/darley-stinger-drone-helicopter-gives-firefighters-eye-in-the-skymgl0v7wxWikBmQgj/
2. Finn P (2011, January 22). *Domestic use of aerial drones by law enforcement likely to prompt privacy debate*. The Washington Post. Retrieved April 28, 2022, from https://www.washingtonpost.com/national/domestic-use-of-aerial-drones-by-lawenforcement-

likely-to-prompt-privacy-debate/2011/01/22/ABLD0MR_story.html
3. Rockman. (2011, July 28). *Micro-copter uavs mapping landslide*. GeoPrac.net. Retrieved April 28, 2022, from https://geoprac.net/2011/07/microcopter-uavs-mapping-landslide/
4. *United States Air Force Unmanned Aircraft Systems Flight* ... (n.d.). Retrieved April 28, 2022, from https://irp.fas.org/program/collect/uas_2009.pdf
5. *Foreword - Federation of American scientists*. (n.d.). Retrieved April 28, 2022, from https://irp.fas.org/program/collect/uas-army.pdf
6. *UAS Roadmap 2005 - Federation of American scientists.* (n.d.). Retrieved April 28, 2022, from https://irp.fas.org/program/collect/uav_roadmap2005.pdf
7. Group M (2012, February 7). *Congress sets 2015 deadline for UAV's to fly in the National Airspace*. Aerospace Manufacturing and Design. Retrieved April 28, 2022, from https://www.aerospacemanufacturinganddesign.com/article/aerospace-unmannedcongress-airspace-020712/
8. Peschel JM (2012, August 1). *Mission Specialist human-robot interaction in micro unmanned aerial systems*. OAKTrust Home. Retrieved April 28, 2022, from https://oaktrust.library.tamu.edu/handle/1969.1/ETD-TAMU-2012-08-11630?show=full
9. Peschel JM, Murphy RR (2013) On the human-machine interaction of unmanned aerial system mission specialists. IEEE Trans Human-Mach Syst 43(1):53–62
10. Hoffman G, Breazeal C (2004) "Collaboration in human-robot teams," In:*Proceedings of the first AIAA intelligent systems technical conference*, p 18,
11. Murphy RR, Burke JL (2008) From remote tool to shared roles. IEEE Robot Automation Mag 15(4):39–49
12. Woods DD, Hollnagel E (2006) Joint cognitive systems: patterns in cognitive systems engineering. CRC Press, Boca Raton, FL
13. Riley JM, Strater LD, Chappell SL, Connors ES, Endsley MR (2010) Situation awareness in human-robot interaction: Challenges and user interface requirements. *Human-Robot Interactions in Future Military Operations*, 171–192. Available at: https://www.researchgate.net/profile/Mica-Endsley/publication/289214913_Situation_awareness_in_humanrobot_interaction_Challenges_and_user_interface_requirements/links/58d711d8a6fdcc1bae96e557/Situation-awareness-in-human-robot-interaction-Challenges-and-user-interfacerequirements.pdf
14. Oron-Gilad T , Chen JYC , Hancock PA (2006) "3. Remotely Operated Vehicles (ROVs) from the Top-Down and the Bottom-Up", Cooke NJ, Pringle HL, Pedersen HK, Connor O. (Ed.) Human Factors of Remotely Operated Vehicles (Advances in Human Performance and Cognitive Engineering Research, Vol. 7), Emerald Group Publishing Limited, Bingley, pp. 37–47. https://doi.org/10.1016/S1479-3601(05)07003-7
15. OpenCV (2022). Available at: http://opencv.org
16. Peschel JM, Duncan BA, Murphy RR (2012) "Exploratory results for a mission specialist interface in micro unmanned aerial systems," In:*Proceedings of the international workshop on collaborative robots and human-robot interaction* (CR-HRI –12), Denver, Colorado
17. Bethel CL, Murphy RR (2010) Review of human studies methods in HRI and recommendations. Int J Soc Robot 2(4):347–359
18. Sauro J, Lewis JR (2010) "Average task times in usability tests: What to report?," In:*Proceedings of the 28th international conference on human factors in computing systems* (CHI '10), pp 2347–2350

Joshua M. Peschel is Assistant Professor of Agricultural and Biosystems Engineering and Black & Veatch Faculty Fellow at Iowa State University. He conducts research in cyber-agricultural systems involving new types of automated sensing and sensemaking.

Brittany A. Duncan is an Associate Professor in the School of Computing at the University of Nebraska-Lincoln. Her research is focused on the intersection of artificial intelligence, human-robot interaction, and unmanned systems.

Robin R. Murphy is Ratheon Professor of Computer Science and Engineering at Texas A&M University. Her research interests are in artificial intelligence, human-robot interaction, and heterogeneous teams of robots.