On the Human–Machine Interaction of Unmanned Aerial System Mission Specialists

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***Abstract*—This paper surveys the human–machine interaction technologies supporting the *Mission Specialist* role in unmanned aerial systems (UASs). The *Mission Specialist* role is one of three formal human team member roles extracted from the UAS-related literature (the others are *Flight Director* and *Pilot*), but unlike the *Pilot* role, the interface needs have not been established. The interfaces used by 17 micro, small, medium altitude long endurance (MALE) and high altitude long endurance (HALE) platforms are examined to determine 1) what type of user interface technologies are present and/or available; 2) how the *Mission Specialist* currently or could interact with the user interface technology; and 3) what are the perceived positive and negative aspects of this user interface technology in the context of the UAS human–robot team roles. Micro and small UAVs pose significant user interface limitations for the *Mission Specialist* role and may produce unintentional interaction conflicts between the *Mission Specialist* role and the *Pilot*, potentially resulting in suboptimal performance and loss of robustness. The survey is expected to serve as a reference for future design and refinement of user interfaces for UAS and a foundation for better understanding human–robot interaction in UAS.**

***Index Terms*—Aircraft display human factors, user interface human factors.**

I. Introduction

THIS paper surveys the state of understanding and human–machine interaction (HMI) practices of the role of the human *Mission Specialist* in collecting mission data with an unmanned aerial system (UAS). The UAS has recently experienced significant technological advancement and permeation into a myriad of modern domains [1], [2], especially military and various search and rescue operations [3]–[6]. UAS operational integration is expected to continue due to the advantages of 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]–[18], [21] and, thus, require HMI for better interfaces and for fundamental concerns such as reducing the human–robot ratio, managing team organizational complexity, and increasing team performance. For the purposes of this discussion, the *UAS* is defined as vehicle plus 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 [22]). Human team members may be colocated with the unmanned aerial vehicle (UAV) platform or at a remote location, and, depending on the type of UAV and mission, can vary in number. Additionally, human team member functional roles may overlap.

HMI research, which is a subcategory of traditional human factors research [20], for specific UAS human team roles does not appear in the literature, presenting a challenge for designers and developers working with current and future unmanned systems. The HMI knowledge void is a barrier to reducing the human–robot crewing ratio through merging human team roles and increasing UAV autonomy [23]–[25], increasing the number of UAVs in a single UAS [26]–[28], and making UAS smaller, more mobile, and available to more diverse domains [29], without first understanding how human team roles are actually interacting. As Hobbs [30] points out, there have been no human factors analyses published on any mobile interfaces for unmanned systems.

This study surveys the *Mission Specialist* role in UAS human–robot teams appearing in over 40 papers covering 17 fielded systems, identifying the hardware and software interfaces. Research and development to improve the HMI of UAS has largely focused on flight and navigation, i.e., the pilot role [31], [32]. An HMI approach to support the acquisition of data and mission-related information remains less well developed [30], [33], particularly for small-scale UAVs [34].

The remainder of this paper is organized as follows. Section II provides an overview of UAS, including UAV operational specifications and human-team roles described in the literature. Section III gives a literature review of the hardware and software interfaces currently used by the *Mission Specialist* role in UAS human–robot teams. Section IV presents the HMI findings for the UAS *Mission Specialist* role from the literature. Finally, Section V presents the conclusions and future directions for this paper. The work is expected to 1) serve as an introduction to UASs for HMI researchers; 2) a reference document for unmanned system designers and developers; and 3) contribute to a better understanding of human–robot interaction in UAS (and in any robot being used for real-time data collection) by identifying the human–machine interfaces used in practice.

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TABLE I
CLASSIFICATIONS OF SELECTED UAVS CURRENTLY IN OPERATION[1]

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

II. UNMANNED AERIAL SYSTEM HUMAN–ROBOT TEAMS

The survey will describe interfaces based on the category of UAV and the role; the background is given here. UAVs are divided into based on size, payload weight capacity, range, altitude, and endurance. Three roles appear in the literature: *Flight Director*, *Pilot*, and *Mission Specialist*.

A. Categories of Unmanned Aerial Vehicles

The composition of a UAS human–robot team depends largely on the complexity of the UAV itself [35]. Therefore, it is useful to provide a summary classification framework of UAVs. This paper will use the four-category classification system employed by the U.S. Air Force [36], [37], Army [38], and Navy and Marine Corps [39]: micro, small, medium altitude long endurance (MALE), and high altitude long endurance (HALE). The categories are shown in Table I. It is noted that for the purposes of this study, focus is restricted to subsonic and suborbital UAVs.

Micro UAVs represent 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 a human team, which is usually colocated, 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.

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 onsite military combat units who will colocate 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 in terms of HMI 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.

MALE UAVs possess a significantly larger endurance than small UAVs and increased mission complexity. Consequently, the size of the MALE vehicles also dramatically increases. The increase in vehicle size permits a significantly larger payload weight capacity, which may consist of not only reconnaissance sensor technology, as well as the ability to transport and remotely deliver munitions to identified targets. MALE UAVs are typically not colocated with their primary human teams, 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. 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 the associated increased payload weight capacity.

B. Unmanned Aerial System Human Team Role Descriptions

There exists a diversity of human team role nomenclature in the literature across the four UAV categories [16], [18], [19], [23], [35], [41], [42]. However, certain human team member role trends are identifiable and, generally, fall into one of three role categories: *Flight Director*, *Pilot*, and the *Mission Specialist*. These three role labels represent a synthesis from the literature and are given in this paper to describe general role function rather than preferred role identification within any specific UAS. A human team member role survey from the current literature is provided for each of the four UAS groups (see Table II).

TABLE II
HUMAN TEAM CHARACTERISTICS FOR THE FOUR GROUPS OF UASS

Group	Flight Director Roles	Pilot Roles	Mission Specialist Roles	On-Site or Off-Site Team Location	Active or Passive On-Site Operation
Micro	Flight Director [18]; Incident Commander [23]	Pilot [18], [23]	Mission Specialist [18]; Sensor Operator [23]	On-Site	Active
Small	Team Commander [41]; Mission Commander [41]	Field Operator [41]	Operator [41]	On-Site	Active
MALE	Data Exploitation, Mission Planning and Communications Operator [16]; Mission Commander [23]	Air Vehicle Operator [16], [42]	Payload Operator [16], Sensor Operator [23]	Typically Off-Site	Passive
HALE	Mission Commander [42]; Mission Planner [42]	Command and Control Officer [42]	Primary Data Exploitation, Mission Planning and Communications Operator [42]; Sensor Operator [42]; Synthetic Aperture Radar Operator [42]	Typically Off-Site	Passive

1) Flight Director: The *Flight Director* role is held by one or more human team members responsible for directing the mission and is described independently in [16], [18], [23], [41], and [42]. Murphy *et al.* [18] define the role of a micro UAV team *Flight Director* as the individual responsible for overall safety of the team members (human and UAV). The *Flight Director* is in charge of mission situational awareness and has the authority to terminate the operation at any point. Cooper and Goodrich [23] describe for a micro UAV team, an *Incident Commander*, who is solely in charge of managing the search effort. For the small UAV category, Oron-Gilad and Minkov [41] ethnographically describe a *Team Commander* role. Serving as the head of the human–robot team, the commander may communicate with other small UAV human–robot teams in the field or control stations and, in addition, monitor the technical condition of the vehicle. More complex situations described did arise requiring an additional individual, a *Mission Commander* (MC), to join the team in order to focus only on strategy and coordination. In the MALE UAV category, Cooke *et al.* [16] define the role of a *Data Exploitation, Mission Planning and Communications Operator* (DEMPC). This team member is solely responsible for planning the actual mission as well as functions as the navigator during the operation. Weeks [42] describes the (MC) as generally the most senior member of the human team, all of which are usually trained as *Air Vehicle Operators* (AVOs). For HALE UAVs, Weeks [42] describes a more distributed command structure for a Global Hawk UAV operation. Here, an MC is present for operation supervision and decision-making, but there is an additional *Mission Planner* (MP) role that would be responsible for developing the flight plan.

2) Pilot: The degree to which one or more individuals is responsible for flight control activity varies. Murphy *et al.* [18] define the role of a micro UAV *Pilot* as responsible for the vehicle within line of sight, while Cooper and Goodrich [23] extends the micro UAV *Pilot* role to include both aviation and navigation. Murphy *et al.* [18] 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. For the small UAV category, higher levels of vehicle autonomy come into play and the formal pilot role may transition to a separate offsite operations control center. Oron-Gilad and Minkov [41] provide detail on a *Field Operator* role that gives input as needed regarding where the vehicle should fly; however, this role appears to have limited flight control and navigation input capabilities. The role of a MALE UAV pilot, as described by Cooke *et al.* [16], is the AVO—the individual who flies the UAV and is in control of its heading, altitude, and airspeed. Cooke *et al.* also indicate a navigation role overlap with their DEMPC, but it is noted that the DEMPC does not participate with any actual piloting duties. Weeks [42] also defines an AVO role that serves as an internal pilot, controlling the MALE UAV from takeoff to landing. When the MALE UAV enters autonomous mode, the AVO monitors flight and occasionally controls the vehicle during data collection. In the HALE UAV category, Weeks [42] provides a description of a *Command and Control Operator* (CCO). The CCO, who is usually a trained pilot, is responsible for flight following, fault diagnosis, and mission monitoring.

3) Mission Specialist: The *Mission Specialist* is the team member responsible for visual investigation and recording and, in more advanced vehicle systems, delivery of an onboard payload. It is a synthesis of roles observed by the authors in [16], [18], [19], [23], [35], [41], and [42]. The *Mission Specialist* role has two interesting components: the responsibility of the role and the location of the role holder.

Murphy *et al.* [18] define the role of a micro UAV *Mission Specialist* as a single human team member solely in charge of collecting reconnaissance data, while Cooper and Goodrich [23] denote a similar role as the *Sensor Operator* (SO) who directs a gimbaled camera for scanning and imagery analysis. Micro UAV mission-related activities 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. In the small UAV group, Oron-Gilad and Minkov [41] describe an *Operator* role that is responsible for looking at specific areas and targets to evaluate the occupancy status of enemy troops and is focused on reconnaissance and the tactical aspects of the UAV mission. Cooke *et al.* [16] define for a MALE UAV system, the *Payload Operator* (PLO), whose main

TABLE III
REFERENCE SUMMARY OF HARDWARE-BASED HMI USED BY A MISSION SPECIALIST ROLE ON A UAS HUMAN–ROBOT TEAM

Group	UAV Platform Name	Heads-Up Display	Isotonic Joystick	Keyboard (full)	Mouse	Trackball	Pushbutton Panel	Touch Screen	Video Display
Micro	AirRobot AR100B®		[44]				[44]		[44]
	Cooper & Goodrich Custom		[40] [23]				[40] [23]		[40] [23]
	Draganflyer X Series	[45]	[45]				[45]	[45]	[45]
	iSENSYS IP-3	[18]	[18]				[18]		
	Like90 T-Rex		[18]				[18]		
	Parrot AR.Drone							[29]	[29]
	Skybotix Technologies CoaX®		[43]				[43]		
Small	AAI Shadow		[48]	[48]			[48]		[48]
	AeroVironment Raven®		[47]				[47]		[47]
	Elbit Systems Skylark®		[41]	[41]	[41]	[41]	[41]	[41]	[41]
	Northrop Grumman Fire Scout		[49]	[49]			[49]		[49]
MALE	General Atomics Predator®		[19] [35] [52] [42]	[16] [19] [35] [52] [42]	[16] [19] [35] [52] [42] [24]		[16] [19] [52] [42] [24]		[16] [19] [35] [52] [42] [24]
	TAI Anka		[54]	[54]	[54]	[54]	[54]		[54]
	IAI Heron 1		[55]	[55]	[55]	[55]	[55]		[55]
HALE	General Atomics Reaper®		[19] [35] [52] [42]	[19] [35] [52] [42]	[19] [35] [52] [42]		[19] [35] [52] [42]		[19] [35] [52] [42]
	IAI Heron TP		[56]	[56]	[56]	[56]	[56]		[56]
	Northrop Grumman Global Hawk		[19] [35] [42] [57]	[19] [35] [42] [57]	[19] [35] [42] [57]		[19] [35] [42] [57]		[19] [35] [42] [57]

responsibility is to control the reconnaissance camera settings and capture imagery. Weeks [42] describes three individual roles that fall under the *Mission Specialist* classification. The *Primary* DEMPC *Operator* identifies target sequences and best collection methods for the UAV. The second role, which is the SO, is responsible for optimal sensor selection and target acquisition, and carries out the directions of the DEMPC. A third ancillary *Mission Specialist*-like role is described for a *Synthetic Aperture Radar* (SAR) *Operator*, who is responsible solely for SAR image capture and target identification. In the case of HALE UAV team roles, Weeks [42] indicates the presence of an image quality control technician, however, does not elaborate nor report information regarding other roles (e.g., DEMPC, SO, SAR, etc.) on the human team. Others have implied that for HALE UAVs, the *Mission Specialist* role may be present in some form on a mission-specific basis [19], [35].

Regarding human team operation, two distinct categories of UAS that are observed are: 1) onsite and 2) offsite. An onsite UAV (micro and small) can generally be transported with the human team for complete launch, control, and landing by the human team. An offsite UAV (MALE and HALE) cannot be transported with the human team; transport, launch, control, and landing are done primarily via other persons at a separate location. In the case of an onsite UAV, there are two categories of human teams involved with a given mission: 1) active and 2) passive. Onsite active human teams (micro and small) control all aspects of the UAV in the field. Onsite active team roles may overlap. Onsite passive human teams (MALE and HALE) in the field tend to only interact with the UAV for activities such as taking reconnaissance imagery, adjusting navigation, etc. For onsite passive human teams, roles tend not to overlap. Offsite human teams (MALE and HALE) tend to exclusively involve some sort of ground control system (GCS) where team members have clearly defined roles.

III. UNMANNED AERIAL SYSTEM MISSION SPECIALIST HUMAN–MACHINE INTERACTION

Seventeen UASs were identified for which either hardware or software aspects of human machine interfacing have been reported in the scientific or trade literature. These UASs are examined for how the human team member in the *Mission Specialist* role specifically interacts with the computer technology available during a UAV mission. The results are synthesized into findings in the following section and populate Tables III and IV.

A. Micro Unmanned Aerial System Mission Specialist Human–Machine Interaction

The HMI for micro UAS is reported for seven systems. However, the *Mission Specialist* HMI is the least well documented among all UAV categories, which may be due to diverse commercial and civilian applications. Fig. 1 provides an example of a *Mission Specialist* interacting with a micro UAV.

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. The *Mission Specialist* role observed the real-time video feed from the T-Rex camera on

TABLE IV
REFERENCE SUMMARY OF SOFTWARE-BASED HMI USED BY A MISSION SPECIALIST ROLE ON A UAS HUMAN–ROBOT TEAM

Group	UAV Platform Name	Aerial Images	API Customization	Menus (simple)	Menus (complex)	Real-Time Video	Synthetic Overlay
Micro	AirRobot AR100B®	[44]	[44]	[44]	[44]	[44]	
	Cooper & Goodrich Custom	[23]				[23]	
	Draganflyer X Series	[45]	[45]	[45]	[45]	[45]	
	iSENSYS IP-3			[18]		[18]	
	Like90 T-Rex			[18]		[18]	
	Parrot AR.Drone	[29]	[29]	[29]		[29]	[29]
	Skybotix Technologies CoaX®		[43]	[43]	[43]	[43]	
Small	AAI Shadow	[48]			[48]	[48]	[48]
	AeroVironment Raven®	[47]	[47]	[47]	[47]	[47]	[47]
	Elbit Systems Skylark®	[41]		[41]	[41]	[41]	
	Northrop Grumman Fire Scout	[49]	[49]	[49]	[49]	[49]	[49]
MALE	General Atomics Predator®	[19] [35] [52] [42]	[19] [35] [52] [42]	[19] [35] [52] [42]	[19] [35] [52] [42]	[19] [35] [52] [42]	[19] [35] [52] [42]
	TAI Anka	[54]	[54]	[54]	[54]	[54]	[54]
	IAI Heron 1	[55]	[55]	[55]	[55]	[55]	[55]
HALE	General Atomics Reaper®	[19] [35] [52] [42]	[19] [35] [52] [42]	[19] [35] [52] [42]	[19] [35] [52] [42]	[19] [35] [52] [42]	[19] [35] [52] [42]
	IAI Heron TP	[56]	[56]	[56]	[56]	[56]	[56]
	Northrop Grumman Global Hawk	[19] [35] [42] [57]	[19] [35] [42] [57]	[19] [35] [42] [57]	[19] [35] [42] [57]	[19] [35] [42] [57]	[19] [35] [42] [57]

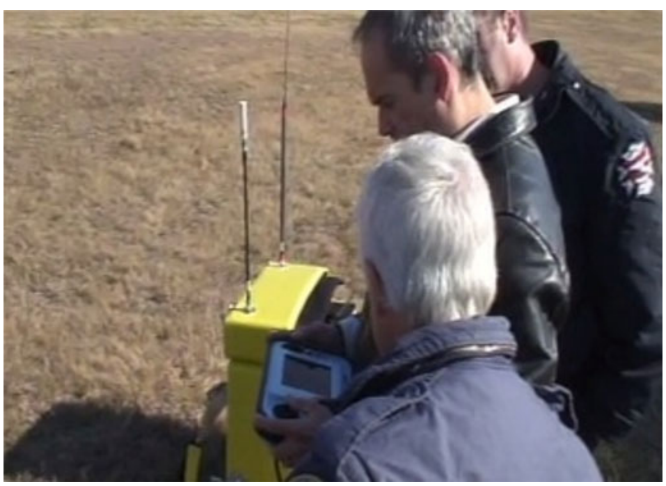

Fig. 1. Example of a micro UAS *Mission Specialist* (Right) interacting with an AirRobot AR100BUAV (Courtesy of Center for Robot-Assisted Search and Rescue).

a separate display screen and used independent radio control hardware for camera positioning. A second study by Murphy *et al.* [18] during a separate post-Hurricane Katrina operation involved the use of an iSENSYS IP-3 rotary wing mUAV. 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. In a study on wilderness search and rescue exercises, Cooper and Goodrich [23] employed the use of experimental, custom fixed-wing micro UAVs fitted with a gimbaled camera. The *Mission Specialist* visualized the video feeds from the vehicle on a display screen and controlled the camera settings using independent radio control hardware.

Although not formally studied in the 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 [43]. 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 [29].

Larger micro UAVs include the AirRobot AR100B, 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 AR100B 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 [44]. 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

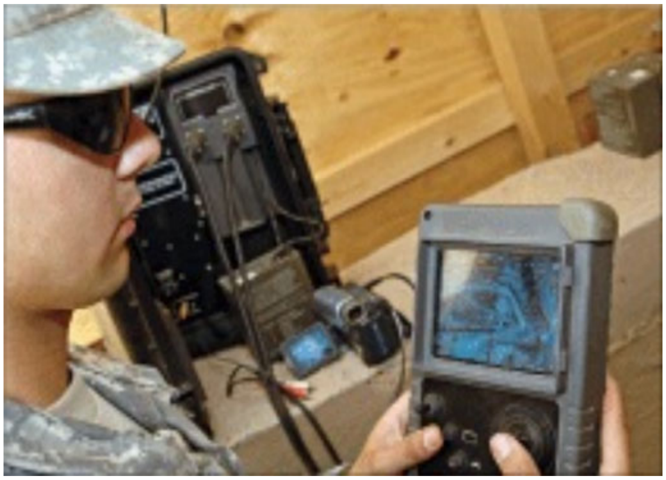

Fig. 2. Example of a small UAS *Mission Specialist* interacting with an AeroVironment Raven UAV (Courtesy of United States Department of Defense).

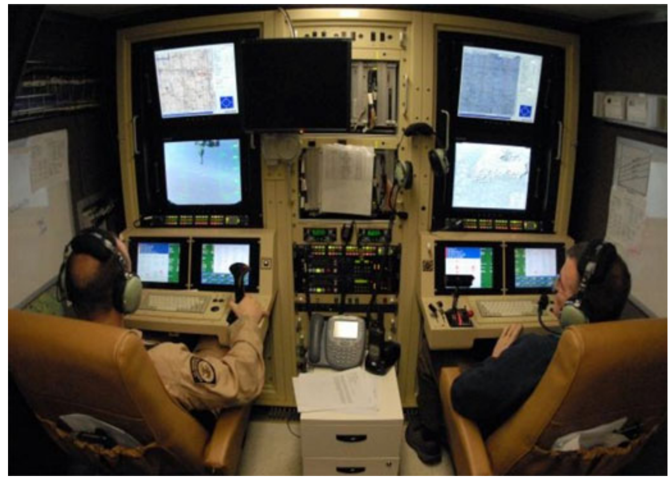

Fig. 3. Example of a MALE UAS *Mission Specialist* (Right) interacting with a General Atomics Predator UAV (Courtesy of United States Department of Defense).

can be broadcast wirelessly to an HUD or a separate display station, thereby allowing a *Mission Specialist* role the ability to complete reconnaissance tasks [45]. 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 [46].

B. Small Unmanned Aerial System Mission Specialist Human–Machine Interaction

The interface technologies for the *Mission Specialist* role have greater variety than that of micro UAS, in part because team members are not always colocated.

Oron-Gilad and Minkov [41] provide two investigations of combat units utilizing a small UAV during the Second Lebanon War of 2006. Both studies indicated that the *Mission Specialist* 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. Fig. 2 provides an example of a *Mission Specialist* interacting with a small UAV.

Commercially available small UAVs typically come with proprietary user interface technology. The fixed-wing Raven, which is produced by AeroVironment, has a common GCS that interfaces with all of the manufacturer's UAV systems. The control device consists of small handheld unit with dual joysticks for flight and navigation. A single small display screen is located at the center of the handheld device, allowing for visualization from onboard cameras. A hardware button-driven menu system allows for camera control. Due to the increased level of autonomy in this system, the *Pilot* and *Mission Specialist* roles overlap, leading to a single operator being essentially responsible for both roles [47]. AAI Corporation produces the fixed-wing shadow line of small UAVs. As with the Raven, the Shadow has a portable GCS. Two operators visualize the mission activities using independent large displays screens. A full keyboard, joystick, and button pad allows for a *Mission Specialist* role to interface with the shadow vehicle [48]. Northrop Grumman produces the Fire Scout, which is uniquely a large rotor-based small UAV. Flight and navigation by two operators is accomplished through a proprietary control system (CS). Consisting of four large display screens—two per operator—the CS displays payload imagery for reconnaissance that would fall under the purview of responsibilities for the *Mission Specialist* role. Interfacing is done through full keyboard, joystick, and button pad controls [49].

C. MALE and HALE Unmanned Aerial System Mission Specialist Human–Machine Interaction

The HMIs for MALE and HALE UAS are discussed together due to operational similarity and the lower count of actual UAVs across both categories. MALE and HALE UAV *Mission Specialist* operations generally rely on satellite communications and involve some type of GCS that is not colocated with a human team on the ground, although there are exceptions. Fig. 3 provides an example of a *Mission Specialist* (right) interacting with a MALE UAV, which is illustrative of HALE UAV *Mission Specialist* interaction as well.

As with small UAVs, MALE and HALE UAV systems normally come with proprietary user interface technology for command and control. General Atomics, manufacturer of the Predator UAVs [50], [51], produces several types of GCS units, ranging from permanent to highly mobile. Interaction by the *Mission Specialist* at the GCS would involve one or more video display screens, a full keyboard, joysticks and mice, and additional ancillary button pads. General Atomics also produces a remote video terminal (RVT), which is essentially a rugged laptop device [52]. A *Mission Specialist* in the field would presumably have access to and control of real-time onboard camera imagery; however, Hobbs [30] indicates that, to date, there have been no human factors analyses published on any laptop-based interfaces for UAV systems. General Atomics also produces the Sky Warrior and Reaper UAVs, which are extended range version of the Predator UAV [53]. Interfacing by the *Mission Specialist* would occur through an RVT and would be expected as similar to that of the Predator UAV.

One simulation study for larger UAS describes aspects of HMI. Cooke *et al.* [16] describe a MALE UAV investigation in a synthetic task environment (STE). In the STE, a single MALE UAV operator was positioned in a GCS-like environment with three large display screens. A full keyboard and mouse were used for interfacing, as well as a variety of pushbutton consoles. The *Mission Specialist* role was responsible for identifying and photographing targets during the simulation.

IV. Unmanned Aerial System Mission Specialist Human–Machine Interaction Findings

An analysis of the *Mission Specialist* role and user interface technology found across all four groups of UAVs results in three findings that the Mission Specialist has dedicated interfaces in MALE and HALE UAS but not micro and small, MALE and HALE UAS use software-based interfaces, while micro and small rely on hardware-based interfaces, and the *Mission Specialist* and *Pilot* roles in micro and small UAS show a high degree of overlap. The last finding suggests a technology interaction conflict that could develop between the *Mission Specialist* and *Pilot* roles for micro and small UAS which would not arise in the two larger UAS categories. The findings are based on Tables III and IV.

Finding 1: The Pilot and Mission Specialist roles have distinctly different interfaces in all categories of UAS except for micro and small UAS, where the Mission Specialist either shares the Pilot-centered display or has a mirrored replica. As seen in Tables III and IV, there are two categories present for onsite human teams: 1) *Pilot*-centered (active), and 2) *Mission Specialist*-centered (passive). *Pilot*-centered technology (micro and small) tends toward active control of the UAV. *Mission Specialist*-centered technology (MALE and HALE) tends toward passive controlling of the camera, taking reconnaissance imagery, etc. Offsite human teams (MALE and HALE) consistently use two separate control stations at which one (or more) separate team member can conduct *Mission Specialist*-related activities.

Finding 2: Mission Specialists in larger UAS tend to have more sophisticated software-based interfaces to collect and interact with images and video, while micro and small UAS are generally limited to hardware-based interfaces. All four groups of UAS involve some sort of hardware-based interface. In micro and small UAVs, hardware interfaces dominate. An onsite active human team *Mission Specialist* tends to interface more with hardware-based technology that is designed predominantly for UAV control and navigation. A micro and small UAV *Mission Specialist* mostly uses handheld controllers that control every aspect of the UAV. In the two smaller groups (micro and small), the *Mission Specialist* was more likely to interact with a limited set of hardware-based input, including only a joystick and/or a predefined pushbutton panel. The actual HMI involved for the onsite active human team *Mission Specialist*, therefore, may take the form of a simple designated pushbutton system for camera angling, zoom, and image capture (e.g., the AirRobot AR100B and DraganFlyer X series). An onsite passive and offsite human team *Mission Specialist* tends to interface more with both hardware-based and software-based interaction technology that is designed more for *Mission Specialist*-centered activities. Most *Mission Specialist* roles in this category use some sort of standard computer (i.e., desktop or laptop) that has a design focus on taking reconnaissance imagery and, possibly, the ability to make navigation adjustments.

In the two larger groups (MALE and HALE), a *Mission Specialist* used the full suite of hardware input devices, including a joystick, keyboard, mouse, trackball, and some type of ancillary pushbutton panel. The reasoning behind this is that a micro and small *Mission Specialist* is more likely to be in a field situation rather than in a controlled GCS environment. In a GCS-based operation, there is suitable workspace for a large set of input devices. The added complexity of the MALE and HALE software environment is also certainly a factor, necessitating a variety of hardware input capabilities. In a field situation, where micro and small UAVs are colocated, mobility is a highly desired characteristic and this will obviously reflect in the interface technology UAV systems as there are normally secondary hardware consoles or mobile nonflight control interface devices available to the *Mission Specialist* role; however, some human team member changeover problems have arisen [30].

Some form of visual display, whether integrated directly into the hardware controller or located at an adjacent or remote base station, was present in all four of the UAV groups. For a *Mission Specialist* in field-type scenarios, displays were generally similar in dimension (14 in or smaller). In GCS operations, for the two larger UAV groups, the visual displays were significantly larger (all greater than 14 in). Some smaller UAV systems found (e.g., the iSENSYS IP-3 and the Aeryon Scout) had HUD capabilities for real-time video feed visualization (although, presumably, any of the UAVs with a standard video signal output could, in theory, be integrated with commercially available HUD or other ancillary display technologies). HUD technologies did not appear to be utilized by the *Mission Specialist* role in the two larger UAV classes. This is most likely due to the nature of the indoor work environment (i.e., controlled lighting), the large visual display screens available, and fatigue issues due to the extended nature of MALE and HALE mission duration.

In terms of the software-based interactions of the *Mission Specialist* role, all four groups were found to have at least one use of static imagery, real-time video, and synthetic overlaying of mission-related ancillary data, as part of the interfacing. Simple menu interaction (i.e., hardware driven menus) was found to be more prevalent in the two smaller UAV groups, while more complex menu interaction appeared in the higher two tier categories. This is due to the greater complexity of interaction required by the larger systems, as well as ties to the greater variety of hardware input devices available to the *Mission Specialist* role. It should also be noted that platform-independent software was observed to take into account a greater variety of hardware inputs [58], [59].

Finding 3: The Mission Specialist role in micro and small UAS has more overlap with the Pilot role, both in spatial proximity and in coordinating functions, than with larger UAS. The onsite active human team *Mission Specialist* found in micro and small UAS tends to work side by side using a single controller designed for a *Pilot*. This type of user interfacing would likely impose a direct interface interaction conflict with the *Pilot* role. The existing user interface design necessitates that the *Pilot* and *Mission Specialist* roles overlap, which violates HMI principles where interfaces are tailored to support distinct roles. For example, in close proximity operations, such as urban or wilderness search and rescue, for example, a *Pilot* may need to focus solely on the flight controls and collision avoidance rather than on *Mission Specialist* tasks such as taking pictures [18], [23].

V. Conclusion

To summarize, three human team member roles (*Flight Director*, *Pilot*, and *Mission Specialist*) were observed in all four operational categories of UAS: micro, small, MALE, and HALE. The current state of HMI practices for the role of the *Mission Specialist* responsible for data acquisition was surveyed for 17 systems. The most significant finding is that the *Mission Specialist* and *Pilot* roles for micro and small UAS, unlike MALE and HALE UAS, share the *Pilot* interface. Sharing violates the HMI principle of dedicated interfaces for distinct roles and suggests an interface interaction conflict that could develop between the *Mission Specialist* and *Pilot* roles in micro and small UAS leading to suboptimal performance and loss of robustness.

The *Mission Specialist* in MALE and HALE UAS had a dedicated software or hardware interface but either shared or used a mirror of the *Pilot* interface for small and micro UAS. Each type of HMI technology consisted of an input mechanism and an output mechanism. Hardware-based inputs included the use of isotonic joysticks, keyboards, mice, trackballs, pushbutton panels, and touch screens. Hardware-based outputs involved heads-up and standard video displays of varying size. Software-based inputs included both simple and complex menus, while software-based outputs consisted of aerial imagery, real-time video, and synthetic overlays. The ability to customize the software interface (i.e., an available API) was also observed for MALE and HALE interfaces.

The user interfaces for MALE and HALE UAS tend to be software-based (e.g., menus, point-and-click, touch, etc.), while the micro and small interfaces tend to be hardware-based (e.g., joystick, buttons, toggle switches, etc.). This dichotomy may be because as the size, complexity, and offsite location of team members in the UAS increase, the enterprise can support a more complex software-based environment with supporting hardware-based input devices.

The dichotomy between software- and hardware-based interfaces impacts how the *Mission Specialist* interacts with the other UAS roles and overall reliability. The *Mission Specialist* role for micro and small UAVs shares the same hardware-based interface with the *Pilot* role, essentially choosing highly mobile hardware-based interfaces at the expense of role separation which HMI principles indicate lead to better performance and more reliable mission execution.

One danger in comparing interfaces across multiple classes of UAS is reconciling differences in domains. However, the main responsibility of the *Mission Specialist* for all UAS and domains includes image and video data acquisition for decision-making, providing a commonality for comparisons.

This survey suggests that more work is needed to create greater user interface independence and flexibility for the *Mission Specialist* role in a micro and smaller UAS. A set of UAS human interface design recommendations should be developed and tested to support optimal levels of independence and flexibility. In the future, it is anticipated that UAV technology, especially in the micro and small categories, will permit more software-oriented customization for general operation and human interaction; therefore, understanding how to optimize individual and team performance through HMI will be important for increasing performance and reducing manpower in UAS operations.

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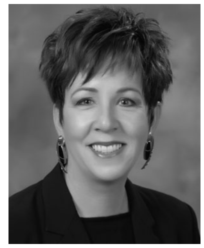

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