Playbook for UAS: UX of Goal-Oriented Planning & Execution

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Abstract. We are evaluating Playbook for CASAS (Connected Autonomous Smart Aerospace Systems), a tool designed to aid first responders in disaster relief efforts. We are adapting an existing tool, Playbook, to support a future unmanned aircraft system (UAS) swarm demonstration. Playbook for CASAS will be used to plan, edit, and monitor simulated UAS swarms, and we are interested in evaluating the user experience of this prototype as well as developing recommendations for future UAS interfaces. Allocation of roles and responsibilities between human-automation systems is key to promoting productive cooperation between users and automation. Future interfaces, however, must allow for adaptive management of the swarm not a constant split in human-automation control. Our early research indicates that when a single pilot is controlling swarms of robotic agents, such as UAS or ground rovers, operators require a higher level, goal-based interface with usability at its core. Along with that high-level control, users can leverage sensors within the swarm to be notified when lower level actions must be taken by the pilot. First responders working in disaster relief efforts require a high level of situational awareness (SA) and precise control at key moments within a mission. This balance in operator workload paired with SA can lead to improved safety and mission outcomes. Our research below outlines leverage points as well as the balance between human involvement and autonomy in UAS interfaces.

Keywords: Swarms, UAV, UAS, Autonomy, Engineering Psychology, Cognitive Ergonomics, User Experience, Human Centered Design, HCI.

1 Introduction

1.1 Future UAS

The field of unmanned aircraft systems (UAS) have seen tremendous growth over the past few decades. Recent advances in hardware have reduced the size and cost of UAS, spurring greater research interest in both government and private industry. The resulting increased availability in this technology has led to a need to provide untrained operators (i.e., operators without explicit pilot training) the ability to monitor and command both individual and swarms of UAS. As the number of UAS in a swarm increases, however, it is important to provide an operator with a user interface that maximizes gains in situational awareness (SA) while simultaneously minimizing the increases in workload associated with managing the additional vehicles. We have designed and evaluated a novel interface for UAS swarm management which requires minimal-to-no training for use by first responders for disaster relief. Using a human-centered design usability study, we have evaluated this interface with first responders, analyzed their feedback, and synthesized recommendations for similar swarm interfaces.

1.2 Situational Awareness

UAS have been embraced by emergency and disaster relief communities for their use in situations where it is either impractical, impossible, or extremely dangerous to deploy first responders. These vehicles can monitor emergency areas, deliver supplies, and search for missing persons, often faster than would be possible with humans and with no risk to their operator. Perhaps more importantly, these vehicles can be used in tandem with first responders already on the ground, providing greater situational awareness and safety in emergency situations. This increase in situational awareness allows first responders to more effectively complete their jobs.

Endsley defines situational awareness as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" [1]. While UAS can provide important SA to first responders on the ground, this should not be a purely unidirectional information flow. The information first responders glean on the ground can be used to redefine the goals of the assisting aircraft. Some tasks, such as modifying the flight plans of UAS, however, requires that first responders also take on the role of air traffic controllers (ATCs). Endsley specifically calls out the "taxing" role of air traffic controllers when she notes that controllers "must maintain up-to-date assessments of the rapidly changing locations of aircraft...and their projected locations relative to each other" [1]. This requirement cannot come without some increase in workload, but a well-designed interface should minimize this impact. The ability to increase situational awareness through the use of live video and other sensor feeds can provide ground workers the knowledge they need to remain safe in highly dynamic scenarios.

1.3 Goal-Oriented Planning

In an ideal scenario, first responders, using the contextual information they've gained on the ground, should be able to control the UAS by pointing them to regions of interest and commanding them to accomplish goals. First responders can use goal-oriented planning in order to minimize the impact of this additional role as ATC. Goal oriented planning can be defined as "the process of breaking down complicated goals into simpler, more manageable sub-goals" [2]. As an example, a first responder may have the goal to search a large fire zone for survivors. This goal can be divided into sub-goals by creating a trajectory of several waypoints which cover the entire fire zone. The goal is then completed when the swarm has searched each of the waypoints. In this scenario, the immediate benefit to the first responder is that they need only assign the system to "search the fire zone" instead of determining and then assigning a complete set of waypoints for the swarm to search.

Goal oriented planning also simplifies the planning process when a first responder has many different goals that need to be completed. As an example, a first responder needs to plan out three goals: "search the fire zone", "deliver a package", and "monitor the waypoint". While each of these goals may contain many sub-goals, the first responder only needs to consider the functional aspects of the goals, such as:

- How long will the goal take to complete?
- How many UAS are required to complete the goal? and
- Which goal has the highest priority?

The first responder can use the answers to these questions to create their plan, without needing to worry about which aircraft will fly to which waypoint at any given time. This allows the first responder to more effectively manage the swarm to respond to current priorities, without needing to concern themselves with the finer details of ATC. This goal level planning has been used by several researchers, with varying numbers of UAS, to result in reduced simulated mission time [3] [4].

2 Interface

2.1 Playbook

Our prototype interface is adapted from the Playbook tool. Playbook is a mobile web-based schedule planning tool currently used in operation by NASA spaceflight analog missions as well as a platform to research crew autonomy. Originally developed as a plan viewer, it was extended significantly in 2014 to become a tool used to enable crew autonomy. These features and capabilities are necessary as we prepare in the spaceflight domain for future deep space missions, where traditional mission control tasks will need to shift to the crew. Shifting these tasks is challenging, as the current roles of mission control are handled by teams of people (100+ in total), where the number of crew onboard may be on the order of 4-6 [5][6].

The use of the horizontal timeline differs significantly from most consumer products where a vertical timeline is used, primarily because of user familiarity with historical mission plans. Apollo mission plans were produced using a vertical timeline layout, but Shuttle and International Space Station mission plans used a horizontal layout [7][8]. As our main target users for the Playbook interface and earlier tools were flight controllers and astronauts who were already accustomed to horizontal mission plan timeline layouts, this was used as a basis for retaining their familiarity. Over the years, however, Playbook team has looked at how the same information would be displayed in a vertical layout. Although we have not done a formal study on the differences, our initial impressions, as we tried to represent the high-density space station or Mars rover plans, is that the readability and flexibility break down in such a scenario [9]. The vertical time layouts tended to rely on vertical text which is difficult to read. When data plots such as power usage or altitude, are displayed on a vertical timeline they become difficult to read and to compare with the timeline. The other main consideration in favor of a horizontal timeline is the heavy use of hierarchy in a mission plan. Each element on the timeline may contain several additional elements (similar to Gantt style charts) that may represent individual activities inside a larger group, or smaller activities that are contained in a larger activity such as on a rover or orbiter mission plan. Three or four levels of hierarchy are not uncommon in these dense mission plans. Since the timeline itself is horizontal, the hierarchy can be displayed vertically, allowing for a natural mapping: higher abstraction are higher vertically compared to lower-level activities. These relationships also map to users familiar with Gantt charts.

2.2 Adapting to UAS

The advantages of providing astronauts with mobile web-based planning tools have benefits and applications that translate over to the UAS space. To support crew autonomy, Playbook was designed with an emphasis to provide lightweight plan editing that allows astronauts to quickly and easily manipulate their mission plan while not taking up time from execution of their spaceflight tasks for the day. Key design goals to enable this were the emphasis on mobile interfaces that allow astronauts to perform mission plan changes without being at a designated computer or console. Emphasis on "walk up and use" usability, and the ability for multiple astronauts to collaboratively work on their mission plan simultaneously was key [5]. These design goals map well to the UAS domain for our use case of first responders arriving at a disaster area. Mobility is key in this UAS context, as our target users are in the field and are not situated at a dedicated console. The target users are not expert pilots and are under similar operational pressures of astronauts, so walk up and use plays a large role in the design and ability to quickly make plan changes. Collaboration allows multiple users to aid in planning, rather than relying on a single user to be designated or otherwise able to accomplish the task at a given time. In addition to the mission planning design elements, the application to the UAS domain required us to integrate time domain planning (used in the Playbook spaceflight mission planning tool) with geospatial planning, which is traditionally seen in many UAS style interfaces. This is represented in the UI by the timeline portion of the interface side by side with the geospatial interface. Depending on what task the user is working on, the timeline or geospatial portion of the interface will grow to maximize the screen real estate, while the non-active portion of the interface will shrink, but not disappear, to allow the user to see the relationship of their planning actions in both the time and geospatial planning domains.

2.3 Interface Elements

Our prototype interface included three main interactive areas which allow users to execute tasks (see Fig. 1). The top of our interface includes a timeline which is very similar to Playbook, but, replaces each crew member row with a single UAS. Each UAS has its own row, followed by a timeline of that UAS future goals and waypoints. Each hour is labeled with a vertical line so users have a sense of when a waypoint or goal will be met or completed.

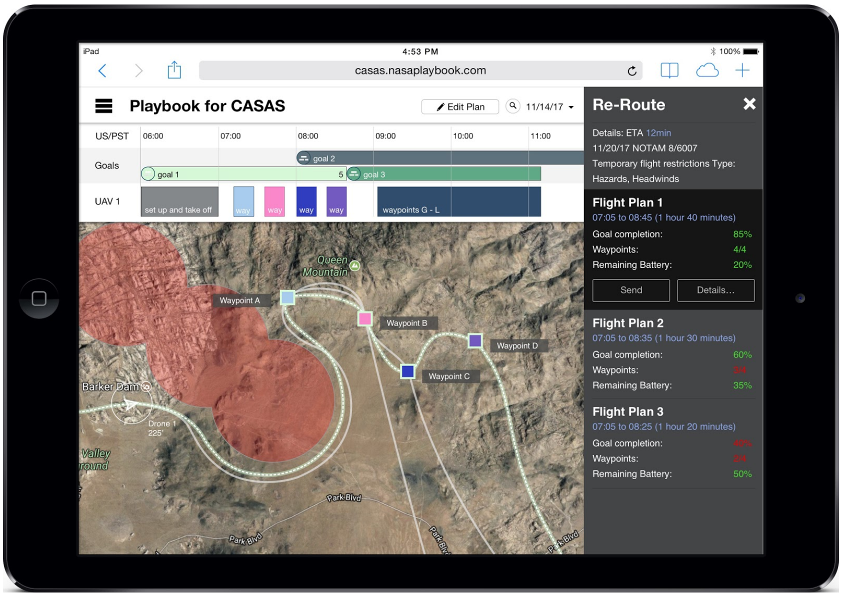

Fig. 1. Playbook for CASAS prototype interface showing the timeline (Top), geospatial view (Center), and stream view (Right). This is showing alternate flight trajectory options, waypoints, and temporary flight restriction (TFR) volumes.

The second area is an overhead or geospatial view, which presents the most radical change to the existing Playbook interface, and much of the focus of our usability studies. This area allows a user to zoom in and out of an area to keep an eye on all UAS, as well as to view trajectories, waypoints, and flight restriction volumes. Users can tap, pinch to zoom, and pan using traditional gestures, although this functionality was not included in our initial prototypes. By leveraging interactions from other widely used products, we can reduce onboarding and training time, especially with the user group of untrained operators.

The last area is the "stream view". In Playbook, the stream view allows users to glean more detailed information, such as temporal information, constraints, and descriptions of each activity. In this prototype, the stream view is used similarly for waypoints. Some additional functionality was also implemented to this area, which makes it, along with the overhead view, the two primary areas of interaction. The stream view appears on the right side of the screen, and slides in and out as needed. It was designed to be visually distinct from the rest of the interface in order to prompt the user to make decisions at key moments within the mission.

2.4 Early Iterations

Early paper prototypes were employed to better understand key elements, button sizing, placement, and to provide a starting point for discussion with our target users.

There are often difficulties early in the design process when it's unclear what functionality should be included or removed after initial exploratory research. A paper prototype, which in this case was simply a cardboard cutout of an iPad with paper taped on top, is useful in the early stages of design (see Fig. 2). Paper prototypes allow quick understanding of the hierarchy of elements and the need for certain actions to be added or removed from the interface. One example of this occurred early in this research with the first version of this prototype. We were interested in displaying UAS prognostics to the user and had the idea to show these metrics for each UAS in a card format. This technique is commonly used in interfaces for single UAS pilots. Once we built this into a paper prototype, however, we quickly realized that allocating prognostics space for each drone was unnecessary and consumed too much space on the iPad. The paper prototype allowed us to recognize those areas that needed to be autonomous, and what information might be unnecessary when guiding multiple UAS. This prognostics card idea works well for individual aircraft management; however, that information is much less relevant to a first responder in the field when guiding a swarm.

Fig. 2. Early paper prototype of a swarm interface. This version has more controls which we later removed like velocity and drone allocation sliders.

3 Methodology

3.1 Research Strategy

For this study, our team built an interactive prototype that was presented to subjects with and without training in UAS management. We then describe a "search and recover" mission using a swarm of aircraft that they must control. We asked each participant to complete tasks which include starting the mission, selecting waypoints, and selecting alternate flight trajectories developed by an auto resolver (AR) algorithm. An auto-resolver is defined as a "trajectory-based conflict resolution algorithm that provides efficient flight path changes to solve medium term conflicts." [10] The auto-resolver used for our upcoming flight demonstration will produce multiple flight trajectories autonomously and use our interface to present these trajectory options to a user. Along with evaluating trajectory selections, we also sought to better understand the role of first responders in the field. To accomplish this, we completed several rounds of early flight tests with three UAS at the NUARC (NASA UAS Autonomy Research Complex), (see Fig. 3).

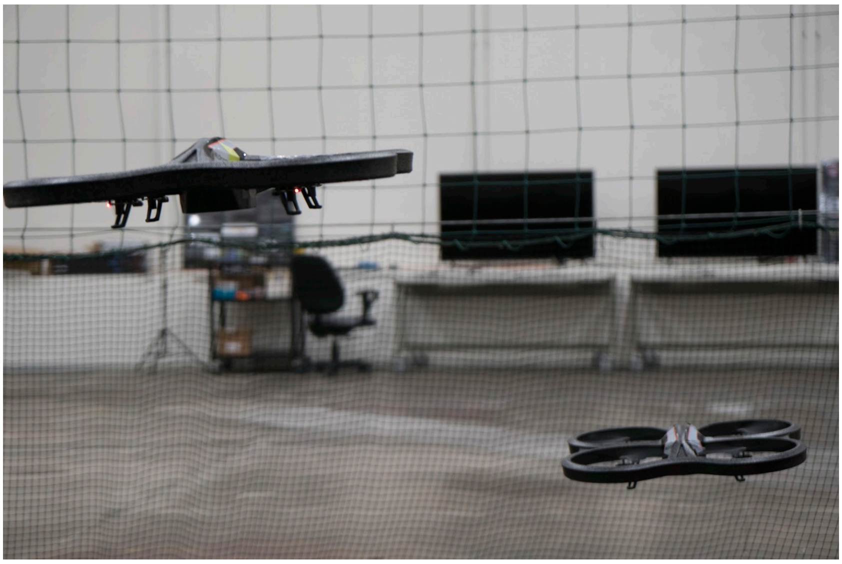

Fig. 3. Initial testing at NASA Ames Research Center in Mountain View, CA. Three drones completing routes planned through the Playbook interface.

To assist us in our research, we recruited seven subjects made up from members of the Ames Disaster Assistance Rescue Team (DART) and UAS researchers from the Human Systems Integration Division at Ames. Our strategy was to evaluate our prototype interface and better understand our users through the analysis of qualitative data from our usability studies. After testing with subjects, we separated data into three categories: our observations, subjective thoughts from the users, and direct quotes. At the end of this first round of testing, we developed key insights and recommendations that both inform and evaluate the design of our prototype as well as future unmanned aircraft systems. Our team's primary method of research is a standard human-centered design iterative evaluation loop that allows for rapid prototyping of interfaces, thereby allowing for multiple rounds of usability testing.

3.2 Testing Protocol

Future UAS studies tailored for users with little-to-no experience in UAS management require building a usability protocol with onboard training. Clear usability protocols are essential to familiarize users with UAS controls and complex disaster relief scenarios. Our usability protocol consisted of defined roles for the subjects, an outline of timing and schedule for testing, an introduction, scenario, tasks for the user, completion criteria, and follow up questions. This structured protocol was created to ensure that the data resulting from these studies was as reliable as possible once we began synthesis of our data. We asked subjects to complete a series of tasks that were framed as messages from a ground control station. During their execution of the task, the subject was asked to think-aloud and try to complete the task on our iPad prototype. A think-aloud study asks the user to verbalize each action they take as well as their thinking while completing tasks [11]. This method allows testers to more easily identify and record pain points or moments of confusion, as well as spot differences in their actions versus their intent. The rationale behind conducting a think-aloud usability study is not only to assist testers in highlighting moments of confusion but also times at which the interface felt most clear to the user. Given the increase in use and availability of autonomous systems, NASA has stated an interest in building requirements for testing human-autonomy interfaces and creating verifiable testing protocols [12].

3.3 User Group and Goals

As noted above, this research was conducted with seven volunteer subjects which consisted of Ames Disaster Assistance Rescue Team (DART) members and UAS researchers from the Human Systems Integration Division at Ames. DART is a federal emergency response and recovery team that can be deployed in support of disaster relief efforts. Previous deployments include the Loma Prieta Earthquake, Oakland Firestorm, Oklahoma City Bombing, and the World Trade Center terrorist attack [13]. Many of our subjects are also members of the CA Task Force 3, a FEMA Urban Search and Rescue Task Force which has separate deployments and training exercises also related to disaster relief. The goal of this research was to gain insight into the human's role in an autonomous UAS traffic management (UTM) systems. We are investigating a network of ground control systems which together produce flight path trajectories that ultimately display to users on an iPad. Future interfaces must allow for sufficient human agency, but a balance between human involvement and automation is at the core of future UAS operations. The innovation in our human-autonomy research was to determine those tasks that can be offloaded to the air traffic management systems and those that must be pushed to the user on the ground. To do this, we must better understand the role of first responders and the needs of this group on the ground.

4 Results

4.1 Introduction

After the first round of testing, we developed a list of insights, recommendations, and behaviors that will inform both our prototype and other unmanned aircraft interfaces. These recommendations and insights highlight user behavior when guiding swarms and underline key leverage points as UAS becomes more ubiquitous. This is by no means an exhaustive study, but is a first step in understanding this complex system within unique mission constraints. It should be noted that these recommendations are pointed towards first responders and firefighters working in disaster areas using unmanned aircraft technology and specifically leveraging swarms.

4.2 Recommendations

Any interface that is designed for walk up and use should provide clear language, and removing air traffic control jargon like NOTAMs is required when designing usable interfaces. NOTAMs are notices to airmen concerning conditions or airspace or hazards usually resulting in a temporary flight restriction and reroute. Our target group has minimal ATC and flight knowledge, so removing this terminology and replacing it with clear language is key to reduce confusion. Another point of confusion with our prototype was that guiding many UAS at once increased the amount of information the user must hold in their head. Clear labels on zones, trajectories, and flight plan options reduce cognitive loads and are essential to assist the user when guiding multiple UAS. Tasks within the geospatial view were also found to be difficult for users because of a lack of clear labels associated with goals and trajectory options. When a user has to hold multiple items in their working memory, like goal completion percentage, waypoints met, and ending battery life for three trajectories, an interface needs to be clear and easily digestible at a glance.

The ultimate goal of the UAS swarm is to increase a user's situational awareness with information gathered by sensors on the UAS. With this in mind, we asked the subjects which sensors would be the most useful during a disaster relief scenario. While subjects responded with a variety of different sensors, they all felt that a live video feed was the most important. Subjects also suggested many other sensors such as heat and radar. Subjects thought heat would be most useful for locating survivors in damaged buildings, and that radar would be useful in gaging heights of those buildings and terrain. While small UAS payloads are extremely limited, we feel that this unique mission environment requires the use of multiple sensors to assist first responders. Providing this sensor data gives first responders more information and tools, enabling greater agency. Users desire agency, and allowing them to control sensors and make real-time decisions on the ground provides freedom to an otherwise fully autonomous system. During our usability study, one participant said, "Pilots don't like being told what to do," and this thought is an important debate between mission planners and operators. Any human-autonomy partnership suggests minimal human involvement from mission planners, however, operators in the field will commonly request more freedom. Current technology is unable to handle every edge case and critical moment, and it's at these times where the human can take over. Real-time sensor data is also key in enabling situational awareness (SA), especially when evaluating a disaster area. Users first need an overall, 360-degree view, then a more detailed view of objectives and points of interest. One subject said, "Scene assessment is the first step, start out high, then focus in", this global SA is critical in high-intensity disaster relief environments.

4.3 Behavior

During testing, we noticed behavior from subjects that informed our thinking surrounding UAS interfaces as well as the choice architecture presented in this interface. We found that subjects hesitated before sending instructions to the swarm and ground control stations (GCS). Go/No-Go indicators were recommended by multiple subjects, and could reduce hesitation when sending alternate trajectories or waypoints to GCS. One subject who had experience operating UAS said, when asked about his hesitation when sending trajectories, "It's a military thing, double check everything". Both his behavior and his thinking at that moment led us to believe that greater affordances were needed to assist users in making these decisions.

During our simulated test, subjects were presented with a temporary flight restriction that required them to change the route of a UAS. After selecting their priority waypoints, the prototype suggested three alternate flight plans for the subjects to choose from. Subjects were presented with a geospatial view of the flight plans, as well as data presenting how long each flight plan would take, what percentage of their goal would be met, and the resulting battery life available after the flight plan was completed. Some users placed importance on hitting waypoints or high percentage current goal completion. Others placed importance on saving battery life for future or upcoming goals. This led us to believe that a clear pre-mission briefing was essential for first responders to prioritize mission objectives. In a real disaster scenario, first responders would have clear objectives, and while we did not instruct them to prioritize time over battery life or mission completion, this prototype allowed them to choose flight paths based off their own experience. It also indicated that the interface was successful in allowing for immediate usability, despite the brief pre-flight introduction.

4.4 Patterns

Several patterns within our data emerged after our usability testing was complete. In particular, when subjects were presented with a temporary flight restriction that required them to select high priority waypoints, users felt they didn't have enough information to make an informed decision. Many subjects requested the time to the next waypoint as well as the time from waypoint to waypoint. We also found that users preferred using both the geospatial and stream view to make these waypoints and trajectory selections. While the timeline view of Playbook presented users with this temporal waypoint information, this was not sufficiently clear, and future prototypes need to address this deficiency.

Along with temporal waypoint information, subjects also asked for weather and wind data to assist them in making future trajectory decisions, as rotorcraft operated by batteries are especially susceptible to weather and wind. If a UAS is flying into a headwind, that information is crucial to a first responder in the field. Lastly, feedback from our usability studies showed an aversion to standard barometric altitude based on sea level. Users felt that absolute altitude (Above Ground Level, or "AGL") was preferred. One of pilots' biggest concerns when dealing with low flying aircraft is running straight into objects without knowing it. AGL has a stronger relationship to topography and ground, which is preferred, especially in the case of mountainous areas where wildfires commonly take place.

4.5 Future Steps & Discussion

We also identified some recommendations that are important, but beyond the technical scope of our upcoming flight demonstrations. Through both feedback from our subjects and observations from testing, we identified that first responders in some cases need to create their own trajectories and requested the ability to drag waypoints. This is preferred when negotiating temporary flight restriction (TFR) volumes as the areas can change from moment to moment - especially when these are caused due to the wildfire itself. Auto-resolver algorithms may not be able to send alternate trajectories fast enough and will not have the same information as a first responder on the ground. For this reason, at critical points such as this, we can offload some waypoint and trajectory planning to the first responder when necessary. Users also need more pre-flight information regarding objectives to make these decisions. This could be a preflight briefing as outlined previously, however, future UAS interfaces should be able relay this briefing back to the user when requested during a mission. After our first round of testing, we realized an additional application for swarm technology was to use UAS to create communication network arrays. One subject during our usability testing described the difficult terrain common in wildfire or earthquake scenarios, which can disrupt standard communication. UAS swarms can provide reliable networks for communication when outfitted with appropriate sensors and antenna arrays [14]. However, due to the cost and weight of this equipment, we have not yet been able to incorporate this technology in future flight tests.

5 Conclusion

5.1 Summary of Results

This research is by no means exhaustive, and is only our first round of testing in preparation for our upcoming flight test. We feel that the insights gathered in this initial research provide cues for future interfaces for both first responders and usable swarm interfaces. Allocation of roles and responsibilities between human-automation systems is key to promoting productive cooperation between these two agents. When guiding a swarm, low-level control should be automated, but, UAS should alert pilots and hand over control at key points within a mission. First responders and firefighters working in disaster areas using unmanned aircraft technology and swarm interfaces need to have a balance between autonomy and workload.

Real-time sensor data is also useful in building situational awareness and notifying users when they should take over control of a single aircraft. Users first need an overall, 360-degree view, then a more detailed view of objectives and points of interest. First responders need to be able to form a mental model of disaster areas to make informed decisions. These sensors can indicate moments within the mission to notify the user when they should take control of single aircraft. Transferring control over a single aircraft to the operator is useful at certain key moments in a mission, however, this manual process can only be performed on a limited number of aircraft at one time [15]. Once decisions need to be made, Go/No-Go indicators could reduce hesitation and confusion in these high-intensity environments. One other method for reducing confusion and cognitive load is to ensure that these interfaces are removing system-oriented terminology, as first responders often do not have ATC or flight knowledge. Removing technical terminology is key to reduce confusion and promote risk reduction. Finally, breaking complex missions into clear goals frame UAS tasks and mission objectives. As the number of UAS and tasks increase within a mission, clear goals provide clarity for first responders.

One of NASA's human research goals is to develop design guidelines for effective human-automation-robotic systems, specifically distributed swarm systems [16]. The use cases for this type of technology include transportation, construction, relief efforts, military, and space applications. Reducing operator workload in these disaster relief environments can lead to improved safety and mission outcomes. The interface presented here is focused on a future flight demonstration at NASA Ames, however, these insights and recommendations can be translated to other swarm applications outside of the use in disaster relief.

When one user is controlling multiple actors in a system, they are no longer concerned with the low-level actions of each aircraft. Goal-oriented planning and higher-level interactions are more useful [17]. This style of goal-oriented planning can reduce cognitive load for the user as they will no longer have to focus on many concurrent tasks being executed by the swarm. Controlling swarms of robotic agents, such as UAS or ground rovers for space applications, requires a higher level, goal-based interface with usability at its core.

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References

1. Endsley, Mica R.: Toward a Theory of Situation Awareness in Dynamic Systems. Human factors 37.1. (1995).
2. Barber, K. Suzanne. Han, David C.: Multi-Agent Planning Under Dynamic Adaptive Autonomy. International Conference on Systems Man and Cybernetics. Institute of Electrical Engineers INC (IEEE). (1998).
3. Jung, Dongwon. Ratti, Jayant. Tsiotras Panagiotis.: Real-Time Implementation and Validation of a New Hierarchical Path Planning Scheme of UAVs via Hardware-in-the-Loop Simulation. Journal of Intelligent and Robotic Systems. (2009).
4. Rasche, Christoph, et al.: Combining Autonomous Exploration, Goal-Oriented Coordination and Task Allocation in Multi-UAV Scenarios. Autonomic and Autonomous Systems (ICAS), 2010 Sixth International Conference on. IEEE. (2010).
5. Hillenius, S.: Designing Interfaces for Astronaut Autonomy in Space. CanUX 2015. Ottawa, Canada. (2015). Invited Speech.
6. Hillenius, S. Marquez, J. Deliz, I. Kanefsky, B. Korth, D. Healy, M. Gibson, S. Zheng, J.: Designing and Building a Crew-Centric Mobile Scheduling and Planning Tool for Exploring Crew Autonomy Concepts Onboard the International Space Station. ISS R&D Conference 2016. Conference. San Diego, CA. (2016). Speech.
7. Space Shuttle Program Flight Data File, https://www.nasa.gov/centers/johnson/pdf/567071main_FLT_PLN_135_F.pdf, last accessed 2018/2/9.
8. Apollo 11 Flight Plan, https://www.hq.nasa.gov/alsj/a11/a11fltpln_final_reformat.pdf, last accessed 2018/2/9.
9. Hashemi, S. Hillenius, S.: @NASA: The User Experience of a Space Station. SXSW Interactive 2013. Interactive. Austin, TX. (2013).
10. Erzberger, H.: Automated Conflict Resolution for Air Traffic Control. Proc 25th International Congress of the Aeronautical Sciences (ICAS). Germany (2006).
11. Ericsson, K. Anders. Simon, A. Herbert.: Protocol Analysis: Verbal Reports as Data. Cambridge, MA. MIT Press (1993).
12. NASA: HCI-05.: We need verifiable requirements that specify standard measurement techniques and metrics for evaluating the quality of user interfaces. (2017). https://humanresearchroadmap.nasa.gov/gaps/gap.aspx?i=329, last accessed 2018/2/7.
13. DART Homepage, http://dart.arc.nasa.gov, last accessed 2018/2/9.
14. Palat, R.C. Annamalau, A. Reed, J.R.: Cooperative Relaying for Ad-hoc Ground Networks Using Swarm UAVs. Military Communications Conference. MILCOM 2005. IEEE, Atlantic City, NJ, USA (2005).
15. Prevot, Thomas. Homola, Jeffrey. Mercer, Joey.: Human-in-the-Loop Evaluation of Ground-Based Automated Separation Assurance for NextGen. The 26th Congress of International Council of the Aeronautical Sciences (ICAS). Anchorage, Alaska, USA (2008).
16. NASA: HARI-02 We need to develop design guidelines for effective human-automation-robotic systems. (2017). https://humanresearchroadmap.nasa.gov/Gaps/gap.aspx?i=334, last accessed 2018/2/9.
17. Lieberman, Henry. Espinosa, Jose.: A Goal-Oriented Interface to Consumer Electronics Using Planning and Commonsense Reasoning. Proceedings of the 11th International Conference on Intelligent User Interfaces - IUI (2007).