Current Challenges in Mission Planning Systems for UAVs: A Systematic Review

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***Abstract*— This paper presents a systematic literature review of mission management user interfaces for UAVs, with the aim of providing insight into the current state of research in this area. A total of 25 relevant publications were identified, and an overview of their content is provided. The review also discusses multimodal interaction approaches presented in these papers and highlights an emerging trend towards a more user-centric design process for UAV user interfaces. The findings of this review contribute to the understanding of existing research and offer guidance for future developments in the design of mission management user interfaces for UAVs.**

Keywords—UAV, Drones, HMI, HCI, human factors

I. Introduction

User interfaces for mission planning of UAVs are an important part of the overall system that is used to control and operate unmanned aerial vehicles (UAVs). These interfaces enable operators to plan, monitor, and execute missions, and should be designed to be intuitive and user-friendly. In recent years, there has been significant research and development in this area, with a focus on improving the efficiency and effectiveness of mission planning for UAVs.

One of the key challenges in the design of user interfaces for mission planning of UAVs is the need to handle large amounts of data and information. UAVs are capable of generating vast amounts of data, including real-time sensor readings, location information, and other mission-critical information. The user interface must be able to effectively process and display this information in a way that is easy for the operator to understand and use.

Another important consideration in the design of user interfaces for mission planning of UAVs is the need for real-time decision making. UAVs operate in dynamic environments, and the operator must be able to make quick and accurate decisions in order to ensure the safety and effectiveness of the mission. The user interface must therefore be able to provide the operator with the information and tools they need to make informed decisions in real time.

In conclusion, user interfaces for mission planning of UAVs play a crucial role in the overall operation and control of UAVs. Effective design of these interfaces is essential for ensuring the success of missions and the safe and efficient operation of UAVs.

In 2017, [1] conducted a meta-analysis to systematically evaluate the current state of research on human-system interfaces for users controlling semi-autonomous UAV swarms. Their analysis provided valuable insights into the advantages, challenges, and limitations of UAV management interfaces at that time. However, the field has continued to evolve rapidly, with new advancements in technology, design, and evaluation methods emerging since then. Given the rapid progress in this domain, this systematic literature review aims to focus partially upon the findings of [1].

More specifically, [1] concluded that there is still a significant need for future research in the area of human-system interfaces for UAV swarms. Among others, their findings stated that there is evidence that incorporating additional user interface types and control modalities can be beneficial. Studies by [2] and [3] demonstrated that adding speech controls, touch interfaces, and other information channels can decrease operator error rates, increase command speed, and reduce cognitive workload, particularly for novice operators. This raises the question: What are the optimal combinations of interface types and interaction modalities (e.g. Head-mounted displays, gesture control, eye- or body tracking), or how can more generalizable guidelines be developed for human-system interfaces? This review aims to give an overview of the publications necessary to answer these questions, but also to give a recommendation on important fields for future research.

Note that our analysis only considered studies published between 2017 and 2023. Due to the extensive work of [1] we considered this time frame as sufficient. Furthermore, we did not exclude studies that also presented research on mission management user interfaces build for non-swarm applications. The intent was to report on general mission management user interfaces.

II. Related Work

As mentioned before, our work partially builds up on the review of [1]. Therefore, this section gives a brief review to their work and at what point we continued to look for current trends and outcomes.

In their 2017 meta-analysis, H[1] systematically evaluated the current state of research on human-system interfaces for users controlling semi-autonomous swarms composed of groups of drones or unmanned aerial vehicles (UAVs). The authors analyzed 27 UAV swarm management papers focused on the human-system interface and human factors concerns, presenting an overview of the advantages, challenges, and limitations of current UAV management interfaces, as well as information on how these interfaces are currently evaluated.

UAV swarms pose several human factors challenges, such as high cognitive demands, non-intuitive behavior, and serious consequences for errors. The authors found that allowing user and mission-specific customization to user interfaces and raising the swarm's level of autonomy to reduce operator cognitive workload are beneficial and improve situation awareness (SA).

Based on their analysis, [1] provided several recommendations for future research on human-system interfaces for UAV swarms. They suggested that UAV swarms should operate above the manual operation level of autonomy (LOA) to reduce the number of direct actions the operator must take in completing a task. Additionally, control interfaces must minimize the amount of UAV and task switching the operator needs to do to preserve SA.

The authors also recommended that future human-system interfaces for UAV swarm control should allow customization based on the user's preferred control and observation mode. Designing the user interface for a given swarm or swarm type can create more intuitive user interfaces that reduce cognitive workload. Moreover, they found that allowing the operator to work 'within' the swarm in a peer-to-peer manner often produces the most efficient results and the least amount of errors, suggesting that human-system interfaces should be designed to facilitate this type of interaction when possible, especially as LOA increases.

Reference [1] highlighted the need for further research on multiple types of feedback (tactile, motion, auditory, augmented reality, etc.), which will likely improve operator SA significantly. They concluded that while much research has been conducted on operators' SA and cognitive workloads when managing a swarm, there are still very few general guidelines that apply across the various uses for UAV swarms. Furthermore, swarm intelligence and control algorithms are constantly improving, which changes the LOAs available to operators and the amount and type of supervision needed by specific swarms. The authors emphasized that the rapidly evolving field of UAV swarm management will continue to expand and grow in the next decade, making an understanding of how operators and UAV swarms interact effectively increasingly vital.

III. Methodology

Our data collection process was oriented at Webster and Watson's (2002) [4] systematic literature review process. This review process involves several key steps, including identifying the research question, searching for relevant studies, selecting studies for inclusion, critically appraising the selected studies, and synthesizing the results.

The first step in the process is to identify the research purpose, which in the case of [4] was to understand the factors that influence the adoption of electronic commerce by small businesses. The authors then conducted a comprehensive search for relevant studies, using a range of databases and other sources to identify articles and other publications that addressed this question. Once the relevant studies had been identified, the researchers then selected the studies for inclusion in the review based on a set of predetermined criteria, such as the quality and relevance of the study, and the reliability and validity of the data. The selected studies were then critically appraised to assess their quality and reliability.

Finally, the results of the selected studies were synthesized, using a range of methods to combine and analyze the data. Authors then drew conclusions and made recommendations based on their analysis of the available evidence. This systematic literature review process is widely regarded as a robust and effective way of conducting a literature review and synthesizing research findings.

IV. Search Process & Descriptive Analysis

While our intention for this review is already explained in the introduction, the next step was to define the search query. With an initial set of relevant terms from the current literature, the query was assembled with domain specific keywords and concatenated with logical operators to ensure that the search engine would consider a broad set of combinations. As a result, the following query was formed and used in the Scopus database (https://www.scopus.com/):

TITLE-ABS-KEY ((“User Interface” OR ui OR gui OR “human machine interface” OR hmi OR “human computer interface” OR hci OR “front-end” OR “ground control station” OR “control panel”) AND (mission OR operation OR journey OR task OR trip) AND (planning OR surveillance OR strategy OR navigation OR management) AND (“Unmanned aerial vehicle” OR uav OR drones OR ucav)

With this query, Scopus applied the search only for the titles, abstracts and keywords of the analyzed document corpus. We assumed that relevant publications mentioned a combination of those terms already in the beginning if the main focus of a paper lies on the human-system interaction; if otherwise it should likely not appear in the search results.

In total, Scopus presented a result list of 478 studies. Due to our envisaged time frame of 2017 until 2023, the results shrunk down to 242 publications. Those 242 papers were then further investigated, initially by an assessment of their titles. If the title of a paper seemed to reflect relevant content, we scanned the abstract and again evaluated this assumption. After the primary selection process, we were left with a total of 53 documents. The final step was to read and consider the entire paper. Finally, we found 25 publications that focused on human-computer interaction and user interfaces for drone management purposes in a broader sense.

Fig. 1 shows the distribution of relevant publications over the span of the last six years. It appears that in 2018 there was a peak of interest in the community for this research domain. However, the selection process of the publications as described above, as structured as it may be, is always biased by the subjective perspective of the authors. Therefore, deeper interpretations are not conducted at this point.

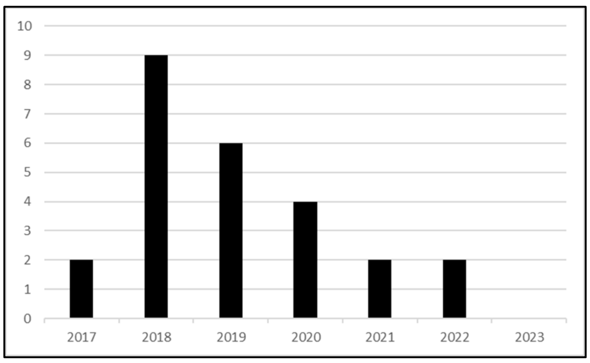

Figure 1: Distribution of relevant publications from 2017 until 2023

The majority of the publications originate from Germany (8), the United States (7), and Italy (4), and most of them are conference contributions (19). In general, they report on early stage research endeavors, proof of concepts, and experiments. Table 1 lists the 25 publications we analyzed in this review.

TABLE 1: LIST OF RELEVANT PUBLICATIONS

Authors & Year	Title
Bachtiar et al. 2019	*Android Application Design as Ground Control Station (GCS) and Waypoint Navigation in Unmanned Aerial Vehicle (UAV)*
Balog et al. 2017	*Examining human factors challenges of sustainable small unmanned aircraft system (sUAS) operations*
Bonny & Abdelsalam 2019	*Autonomous navigation of unmanned aerial vehicles based on android smartphone*
Castillejo-Calle et al. 2019	*A multi-UAS system for the inspection of photovoltaic plants based on the ROS-MAGNA framework*
Chandarana et al. 2018	*Challenges of using gestures in multimodal HMI for unmanned mission planning*
Di Vincenzo et al. 2022	*A Natural Human-Drone Embodied Interface: Empirical Comparison With a Traditional Interface*
Ellwanger et al. 2018	*Axisplus Content-based Control for Camera Drones: Design and evaluation of user interface concepts*
Feuerriegel et al. 2021	*Interface Design for Human-Machine Collaborations in Drone Management*
Friedrich et al. 2020	*A Multi-UAS platform to accelerate situation assessment in first response missions - Identification of user needs and system requirements using design thinking*
Gale et al. 2018	*Playbook for UAS: UX of goal-oriented planning and execution*
Goricanec et al. 2021	*Civil infrastructure data acquisition in urban environments based on multi-UAV mission*
Hutton 2019	*Augmented reality interfaces for semi-autonomous drones*
Jie et al. 2017	*Design of multi-mode UAV human-computer interaction system*
Kosch et al. 2018	*DronectRL: A tangible remote input control for quadcopters*
Lim et al. 2018	*Avionics Human-Machine Interfaces and Interactions for Manned and Unmanned Aircraft*
Liu et al. 2018	*Usability Evaluation for Drone Mission Planning in Virtual Reality*
Luongo et al. 2019	*Human Machine Interface Issues for Drone Fleet Management*
Meyer and Schulte 2020	*Operator Controlled, Reactive UAV Behaviors in Manned-Unmanned Teaming Scenarios with Selective Datalink Availability*
Miehlbradt et al. 2018	*Data-driven body–machine interface for the accurate control of drones*
Okamura and Yamada 2020	*Calibrating Trust in Human-Drone Cooperative Navigation*
Ramirez-Atencia & Camacho 2018	*Extending QGroundControl for automated mission planning of Uavs*
Rivalta et al. 2020	*Facial Expression Analysis for Cognitive State Estimation in Aerospace Human-Machine Systems*
Rudnick and Schulte 2017	*Implementation of a responsive human automation interaction concept for task-based-guidance systems*
Segor et al. 2019	*Controlling swarm complexity: A management by objective approach*
Temme et al. 2022	*Traffic and mission management in the ResponDrone project*

V. RESULTS & DISCUSSION

A. General Overview

Our initial synthesis of the 25 publications represents the results of this review. We gathered the relevant attributes of each paper for our purpose in form of a matrix (due to its size, the complete matrix is not inserted here but available at: *tinyurl.com/4ucvr8xm*). The majority of these attributes were chosen according to the ones [1] used:

- The aim of the publication
- The type of the study
- The number of participants (if available)
- The data that was gathered in the study
- The type of the mission or the purpose of the system
- The scope of the study (is it a specific use case or a more general purpose?)
- The outcomes

Taking a closer look at the types of the studies shows, that most of the publications are primarily proof of concepts (8) or experimental evaluations (9). The "proof of concept" papers demonstrated ideas and designs like an Android-based Ground Control Station (GCS) [5], [6], a dedicated user interface and a system architecture to facilitate UAV missions to collect data of civil infrastructure [7] or a Virtual Reality (VR) based interface [8].

The studies mentioned focus on various aspects of human-swarm interface designs for UAV control, aiming to improve usability, efficiency, and safety. Reference [9] describe the architecture and capabilities of the ResponDrone platform, emphasizing the importance of automated traffic and mission management for first responders. Reference [10] focus on enhancing UAV autonomy and reducing operator workload through automated mission planning and real-time replanning, extending the capabilities of the QGroundControl simulation environment.

Reference [5] propose an Android-based ground control station (GCS) application that increases user mobility and reduces reliance on personal computers. Reference [6] present a smart GPS quadcopter navigation system controlled through an Android-based interface, showing the system's potential to expand drone operations across industries. Reference [8] aim to improve military UAV control and mission planning by incorporating virtual reality and artificial intelligence technologies.

Reference [11] describe a system architecture and human-system interface for mission management at a photovoltaic plant using UAS teams, demonstrating its applicability in real-world settings. Reference [7] address the challenges of multi-agent UAV systems by proposing an effective mission planning interface that includes telemetry data, data download/upload, a trajectory planner, and data representation. Reference [12] propose a method for increasing UAV controllability during data link outages by allowing pilots to define automatic behaviors and constraints, discussing potential benefits and complexities for contingency planning and resilience in military and civilian use cases.

These studies share a common goal of enhancing the efficiency, safety, and user experience of human-swarm interfaces in UAV control systems. They explore various aspects of interface design, including mission planning and management, autonomy, adaptability, and the integration of novel technologies. By synthesizing these studies, we can identify key themes and advancements in the field of human-swarm interfaces for UAV control:

- **Mission planning and management:** Several studies, such as those by [4], [6], and [7], emphasize the importance of effective mission planning and management to reduce operator workload and improve mission success.
- **Autonomy and adaptability:** Studies like those by [10] and [12] explore the role of autonomy in reducing operator workload and ensuring system resilience during data link outages.
- **Mobile and accessible interfaces:** Reference [5] and [6] propose Android-based control systems to increase user mobility and make UAV control systems more accessible.
- **Integration of novel technologies:** Studies such as those by [8] and [11] explore the potential of integrating virtual reality, artificial intelligence, and other cutting-edge technologies in human-swarm interface design.
- **Real-world applications and testing:** Many of the studies, like those by [11] and [7], highlight the importance of testing proposed solutions in real-world settings, demonstrating the practical applicability of their findings.

In summary, the “proof of concept” studies share a focus on improving operator experience, integrating technology, enhancing mission planning and automation, addressing real-world applications, and conducting thorough evaluation and testing. Collectively, they contribute to a better understanding of how to develop effective user interfaces and mission planning systems for UAVs in various contexts.

The studies that included experimental evaluations have a slightly different focus although there are obviously intersections.

Reference [13] focused on the usability of VR interfaces for drone control within the ISAACS project, developing an evaluation framework for iterative user testing and prototyping. Reference [14] designed and validated an immersive interface for managing UAV fleets, addressing both functional and non-functional requirements while reducing cognitive load and improving task performance.

Reference [15] explored facial expression analysis for cognitive state estimation in one-to-many scenarios, intending to support the design of adaptive One-To-Many systems and Human Machine Interfaces and Interactions (HMI2). Reference [16] compared the usability of a so called Natural User Interface (will be explained in the next subsection) with a traditional interface for distal control of simulated drones, introducing dAIsy as a flexible software for various input devices and robotic platforms. Reference [17] investigated efficient and uncluttered user interfaces for camera operators controlling drones in a cinematic context, conducting user studies to evaluate design alternatives and clutter reduction.

Reference [18] presented DroneCTRL, a tangible pointing device designed to simplify quadcopter control for non-expert users, demonstrating improved precision and accuracy. Reference [19] developed a data-driven body-machine interface (BoMI) for intuitive and efficient control of drones through spontaneous gesture-based interactions, enabling users to quickly master drone control. Reference [20] proposed an adaptive trust calibration framework for continuous cooperative tasks with autonomous systems, successfully applying the method of semi-automatic drone navigation. Finally, [12] developed a task-based guidance system for reconnaissance UAVs, aiming to improve Manned-Unmanned Teaming (MUM-T) and reduce operator workload through responsive adjustments in communication and status feedback.

These studies share a common focus on improving human-swarm interfaces for controlling drones and UAVs, addressing various challenges such as usability, cognitive load, operator workload, and adaptability. They all aim to enhance human-system interaction, enabling users to effectively manage and interact with autonomous systems in diverse contexts. The studies employ different techniques, ranging from VR and natural user interfaces to gesture-based controls and adaptive trust calibration frameworks.

The synthesis of the studies can be broken down into five key aspects:

- **Usability:** The interfaces should be easy to learn, use, and adapt to, ensuring that users with varying levels of expertise can effectively control and interact with UAVs [13], [14], [16].
- **Cognitive Load Reduction:** Interfaces should minimize cognitive load and operator workload, enabling users to maintain situational awareness and make better decisions in complex environments [15], [17].
- **Adaptability:** The interfaces should be able to adapt to different contexts, user preferences, and cognitive states, dynamically adjusting the level of automation support and information presentation [14], [20].
- **Intuitive Interaction:** Incorporating natural and intuitive interaction modalities, such as gestures, tangible devices, and immersive environments, can enhance user engagement and control over UAVs [16], [18], [19].
- **Trust Management:** Designing interfaces that foster appropriate trust levels in autonomous systems, balancing reliance and vigilance, can lead to more effective collaboration between users and systems [20], [21].

Their work contributes to the development and design and evaluation process of user interfaces for various user needs and application scenarios.

B. Multi-Modal User Interfaces

As described before, this review would also analyze the current state-of-the-art research regarding multi-modal designed interfaces. The last section already mentioned a few examples which shall be reflected on here more in detail. Our question was what has happened in the last six years within the community in terms of ideas, prototypes and evaluations.

In total, 12 of the 25 publications to a certain degree dealt with the aspect of multi-modal interactions for user interfaces for drone management. Table 2 gives an overview of the prototypical interaction modalities. The mainly used systems are Virtual and Augmented Reality Systems (3) as well as touch devices like computer tablets (4). The reason for that could be a comparatively easy to build or affordable to buy technological setup compared to an eye- or body-tracking system. However, most of the studies can be assigned to a Natural User Interface (NUI) approach. Despite the significance of usability in human-system interaction, a majority of widely used devices remain inaccessible to all potential users. Specifically, users with limited or no technological experience, or those with special needs, necessitate thoughtfully designed systems and user-friendly interfaces that prioritize recognition over recall. In this context, NUIs serve as an efficient approach, as they facilitate user learning through interface features that resemble humans' innate sensorimotor interactions with their surroundings [16].

TABLE 2: MULTI-MODAL INTERACTION MEANS

	VR/AR	Touch	Gestures	Eye Tracking	Facial Expression	Upper Body	Pointing Device
Bachtiar et al. 2019		■					
Bonny & Abdelsalam 2019		■					
Chandarana et al. 2018			■				
Di Vincenzo et al. 2022			■	■			
Ellwanger et al. 2018		■					
Gale et al. 2018		■					
Hutton 2019	■						
Jie et al. 2017	■						
Kosch et al. 2018							■
Liu et al. 2018	■						
Miehlbradt et al. 2018			■			■	
Rivalta et al. 2020					■		

Authors in table 2 focus on the development and evaluation of multi-modal interaction techniques for UAV mission management user interfaces. They emphasize the importance of making these interfaces more intuitive, efficient, and accessible, especially for non-expert users.

Reference [22] advocate for the use of gesture-based natural language interfaces, highlighting the importance of system feedback in helping users understand the boundaries of gesture interaction. Reference [16] explore the potential of eye-tracking and hand gesture recognition, noting that further work is required to achieve a level of naturalness that outperforms traditional input devices.

As already mentioned before, [18] introduce DroneCTRL, a tangible pointing device designed to simplify quadcopter input and operation. Their findings demonstrate that DroneCTRL, even without visual feedback, leads to lower task completion times and higher precision compared to other input modalities. Reference [19] develop a data-driven body-machine interface that allows for intuitive and efficient control of drones through gesture-based interactions. Their study shows that inexperienced participants using a torso strategy significantly outperformed joystick users and achieved comparable performance to a bird-flight simulator.

Lastly, the facial expression analysis for cognitive state estimation of [15] supports the idea that the integration of such a feature into a sensor network for Cognitive HMI2 can enhance the accuracy and reliability of cognitive state estimation, contributing to operational safety in the growing field of unmanned aircraft system (UAS) services.

In summary, these studies emphasize the importance of multimodal interaction in UAV mission management user interfaces, with the goal of making them more intuitive, efficient, and accessible to a broader range of users [15], [16], [18], [19], [22].

Summarized, there clearly is a notable trend towards research about multi-modal interaction concepts for UAV mission planning systems and interfaces. However, we can support [1] in their findings, that more research is needed at this point.

C. User-Centric Design Process

A further trend we noticed in our review is an emphasis on user-centric design processes. The key aspect of a user-centric design approach is to prioritize the needs, preferences, and experiences of the end-users in the design process. This approach aims to create products or interfaces that are usable, accessible, and satisfying for the people who will ultimately interact with them [23], [24].

Following the explanation of [15], many technological advances lack a user-centric perspective, leading to increased cognitive complexity and stress for operators managing complex and dynamic environments [15]. Hence, we took a closer look at those studies that involved experimental settings including participants. Whether the design process of a prototype is clearly classified as user-centric or not is not always completely explicit. Therefore, we want to highlight and promote those studies that clearly mention and describe their user-centric approach.

For instance, the study of [17] focuses on creating a user-centric interface for movie camera operators, aiming to simplify the complex task of object tracking in an aesthetically pleasing manner. The researchers conducted two user studies to evaluate design alternatives and minimize visual clutter in the interface by adopting the design according to the operators' cognitive abilities. They developed a functional prototype incorporating a progressive reduction adaption strategy to reduce occlusion. The study found that their design decisions effectively reduced clutter without negatively impacting workload, control, creativity support, or precision.

The work of [14] involves multiple design iterations and incorporates quantitative and qualitative feedback to tackle information asymmetries caused by latency in information exchanges. The study validates the interface design through several experiments, demonstrating reduced cognitive load and improved task performance. Overall, this work has implications for designing interfaces that enhance human-system collaboration and allow for effective interaction with automated systems like UAVs.

Reference [25] published their user-centric approach also in the ResponDrone project, which focuses on developing a multi-UAS platform for first responders during large-scale natural disasters. Using design thinking methodology, user needs and system requirements were gathered from 18 stakeholders during a two-day workshop. This user-centric approach led to prototype mock-ups of the platform's user interface and concepts for effective flight planning, deconfliction, and risk detection and mitigation, emphasizing the importance of considering user needs during development.

The design and evaluation approach of [26] includes onboard training, clearly defined roles, timing and schedule, an introduction, scenario, tasks, completion criteria, and follow-up questions. To ensure reliability, a think-aloud study was conducted, asking users to verbalize their actions and thoughts while completing tasks on an iPad paper prototype, allowing the identification of pain points and moments of clarity.

VI. CONCLUSION & FUTURE RESEARCH

Adopting a user-centric approach to design, prototype, and evaluate drone mission management user interfaces is crucial for enhancing usability, satisfaction, and overall effectiveness. By involving users early in the design process, designers can better understand the needs, preferences, and cognitive processes of the end-users [27]. This understanding allows designers to tailor the interface to the specific requirements of drone operators, improving the ease of use, efficiency, and safety of the system [28].

In contrast, including users later in the design process can lead to suboptimal designs that fail to address critical user needs, resulting in systems that are difficult to use or do not align with user expectations. Consequently, these designs may require costly and time-consuming iterations or redesigns to address usability issues [29]. Early user involvement can also facilitate the discovery of unanticipated user requirements, enabling designers to address potential issues proactively and enhancing the overall user experience [30]. Hence, a user-centric design processes for drone mission management user interfaces is essential for creating intuitive, efficient, and user-friendly systems that meet the needs of operators and facilitate effective mission management.

Moreover, we underline that user interfaces that include multi-modal interaction can substantially enhance usability, efficiency, and overall user satisfaction. Multi-modal interaction, which combines various input and output modalities, such as touch, speech, gesture, and visual displays, can provide users with a more flexible, intuitive, and effective means of interacting with drone systems. By leveraging the strengths of different modalities, multi-modal interfaces can improve information processing, reduce cognitive workload, and facilitate faster and more accurate decision-making [31]. Furthermore, multi-modal interaction can accommodate individual differences in user preferences and abilities, enhancing accessibility and inclusivity in drone mission management systems as we saw earlier.

Based on our conclusions, we recommend future research to focus more on user-centric design processes in order to reduce training times, error rates and the operators' technology acceptance. Finally, we support and underline [1] call for more endeavors towards multi-modal interaction principles to facilitate and enrich UAV mission management systems.

An important limitation to be mentioned here, is that an extension of our work might benefit from additional literature search engines and databases other than Scopus.

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