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Challenges and Future Directions for Human-Drone Interaction Research: An Expert Perspective

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ABSTRACT

Drones are likely to enter social spaces in the foreseeable future. Novel Human-Drone Interactions (HDI) will foster beyond typical drone-operator interaction, posing new human factors challenges. However, the specific focus areas for HDI research remain unclear. This study conducts 11 expert interviews to identify potential use cases and human factors challenges for HDI in public spaces. Initial drone use cases include emergency response and delivery scenarios, where the general public may interact as recipients and bystanders, each posing unique challenges. Uncertainty, stemming from a lack of awareness, emerges as a significant human factors concern, impacting perceived risk. Addressing this uncertainty, especially in recipients, may involve refining drone behaviour, physical appearance, and interface design. The challenges identified in this study lay the groundwork for future HDI research in public spaces.

KEYWORDS

Human-drone interaction; interview study; drone applications; human factors

1. Introduction

We are currently experiencing a new generation of technology characterised by pervasive computing, wherein robots like drones[1] are integrating into our daily routines (Wojciechowska, Frey, Mandelblum, et al., 2019). According to Fortune Business Insights (2024) report on the global consumer drone market, the demand for drones is projected to grow more than six times from 8.77 billion dollars in 2022 to 54.81 billion dollars in 2030. Herdel et al. (2022) identified over 100 use cases for Human-Drone Interaction (HDI), ranging from leisure to professional activities, including aerial photography, delivery, and emergency response. Some of the use cases benefit the public and require them to actively interact with drones more than other use cases. For example, a medical supply delivery drone requires humans to coordinate with the drone and collect the necessary medical equipment (Sanfridsson et al., 2019), in contrast to a drone performing a light show to entertain humans (Jorgenson, 2020). With the introduction of drones into the public domain, there are concerns regarding human factors and public acceptance that need to be considered. Identifying the most probable short-term use cases can guide ongoing research and assist designers in addressing specific challenges. Understanding the intended use cases and their challenges helps researchers design drones that meet the user needs for those scenarios, increasing the likelihood of people accepting drone integration (Lidynia et al., 2017).

Interaction with drone technology is relatively a new phenomenon for the public. Humans may interact with drones as operators by remotely controlling the drone (Tezza & Andujar, 2022) or perhaps as recipients by receiving a package from a delivery drone (Diaz, 2017). According to a web article on US drone statistics (Vuleta, 2021), only 15% of US residents have experience in flying a drone. As a result of current safety regulations (Federal Aviation Administration, 2024), the proportion of humans interacting with a delivery drone to receive a package is probably even lower. Regardless, the demand for drones is expected to increase in the foreseeable future, leading to a rise in human-drone interactions. Due to a lack of exposure to such interactions, humans are likely to experience feelings of uncertainty (henceforth, referred to as uncertainty). Uncertainty could lead to human factors issues, like a lack of trust (Chiou & Lee, 2023; Lee & See, 2004), possibly affecting the acceptance of drones. In order to handle uncertainty and the resulting human factors issues, a possible research direction is to identify and address challenges emerging from HDI.

Past studies made efforts to understand use cases, human-roles, challenges and opportunities for future research on HDI. Previous literature reviews (e.g., Baytaş et al., 2019; Herdel et al., 2022; Tezza & Andujar, 2019) provided a comprehensive overview of current state-of-the-art drone use cases and human-roles. However, the reviews did

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not identify the likely initial use cases in public spaces that can be used to infer human factors challenges. While some interview studies (e.g., Ljungblad et al., 2021; Tezza & Andujar, 2022; Yao et al., 2017) primarily focused on the operator's viewpoint, exploring themes that are beyond human factors, such as professional considerations, flight preferences, and privacy perceptions, others (Alon et al., 2021; Khan & Neustaedter, 2019) delved into the recipient's needs and interaction scenarios for a typical firefighting use case. There is a gap in identifying and addressing human factors challenges associated with the introduction of drones in public spaces that extends beyond these typical use cases.

In order for drones to be introduced in public spaces, there is a need to identify the potential use cases for HDI and their respective interaction challenges from a practical perspective. This study addresses the gap by interviewing field experts to identify relevant use cases and major human factors challenges in HDI. Our study complements the current state-of-the-art user-centred design for HDI by exploring practical insights from industry, research institutes, and academia. It provides valuable research directions for early-stage human factors researchers and drone designers to prioritise in the coming decade.

The key contributions of this study are:

1. Provides insights into the human factors that are relevant for the potential HDI use cases in public spaces.
2. Distinguishes between the roles of bystanders and recipients and their respective challenges.
3. Identifies and addresses critical human factors challenges for both trained and untrained individuals.

2. Background

Past research investigated HDI from the perspective of the human-role, use case and drone design (Albeaino et al., 2022; Baytaş et al., 2019; Herdel et al., 2022; Tezza & Andujar, 2022). In the previous user studies (e.g., Brock et al., 2018; Cauchard et al., 2019; Herdel et al., 2021; Obaid et al., 2015; 2020; Yeh et al., 2017), drones were intentionally designed for specific contexts, and participants were well-informed about the drones and their capabilities. The general public seldom encounters drones and lacks knowledge about them, possibly resulting in feelings of uncertainty (Meissner et al., 2020). Uncertainty may arise regarding the specifications of the use case, the roles of individuals in it, and the interpretation of the drone's intentions through its design elements, especially when the individuals are untrained to interact with drones in public spaces (Clothier et al., 2015). Below is a brief overview of relevant prior research and concerns, regarding human-roles, use cases, drone design, and the concept of uncertainty.

2.1. Human-role

Human-roles have been previously classified as operator and recipient based on the level of control for autonomous drones (Baytaş et al., 2019; See Figure 1). An operator uses

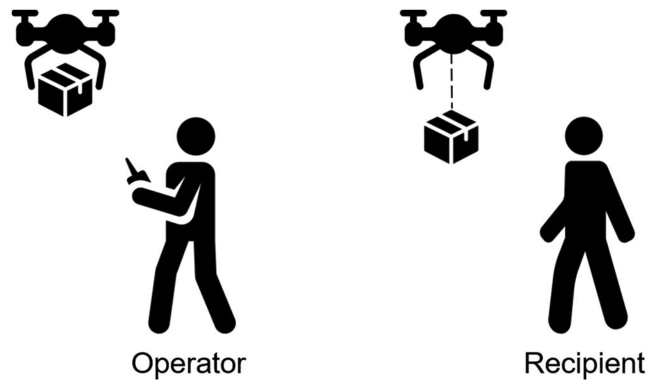

Figure 1. Two categories of human-roles in HDI, namely: operator and recipient (Baytaş et al., 2019).

an interface (e.g., joystick controller) to control the drone remotely and to perform a task (e.g., hobby flying). A recipient, also referred to as a bystander by Baytaş et al. (2019), may not necessarily control a drone but aims to benefit from an interaction with a drone (Tezza & Andujar, 2019). For instance, a pedestrian receives navigational information from a drone (Colley et al., 2017).

Drones are likely to become more automated, changing the task of the operator from actively controlling the drone to supervising its actions and intervening when necessary (Tezza & Andujar, 2019). Each role has different requirements in terms of information and interface, resulting in unique design challenges. For example, a few design challenges for the role of an operator include (i) managing ambiguity arising from information asymmetry due to mismatched goals between automation and the operator during drone fleet management (Feuerriegel et al., 2021); (ii) supporting operators by identifying and providing "appropriate" information (e.g., control- and situation-based) to achieve a safe transition of control in automated drones. A few design challenges for the role of the recipient include (i) determining the informational needs necessary for a natural interaction; and (ii) designing the drone aesthetics and feedback based on the recipient's expectation on the use case (c.f., Balasubramaniam et al., 2023; Karjalainen et al., 2017; Tan et al., 2018).

The number of potentially useful drone applications that involve not just the typical drone-operator interaction is vast, yet research in these areas is scarce. There could be interactions where both an operator and a recipient play an important role by supporting each other while interacting with the drone. For example, in a complex fire emergency, situational awareness for a remote drone operator might be limited, whereas a firefighter close to the incident has a better awareness of the situation and where the drone's assistance is needed (Alon et al., 2021). In these situations a transfer of control might be beneficial, so that the drone can be used optimally. However, there is a lack of literature exploring natural methods to transfer the control between different human-roles. Interactions may involve scenarios where a drone, such as a social drone, interacts with multiple individuals (Fernandez et al., 2016), or an individual interacts with multiple drones (Braley et al., 2018; Cacace et al., 2016; Fedoseev et al., 2022), with potential applications in search and rescue missions or forest firefighting scenarios. In such multi-agent or multi-user interactions, especially in public spaces, ambiguity may arise due to limitations in the resolution and scalability of communication with the target individual or group, leading to challenges in communication and control for individuals (Cauchard et al., 2021).

2.2. Use cases

In a user-survey study conducted in Switzerland by Klauser & Pedrozo (2017), participants showed a preference for drones in military and police applications over commercial and hobby uses. While drones are extensively used in military and police operations (NL Times, 2020; Satam, 2023), their interaction with untrained individuals, such as recipients, is minimal, as they are typically operated remotely by trained personnel. There is a growing interest in use cases beyond these domains, ranging from medical supply and package delivery to entertainment shows (Crockford, 2023; Riedel, 2023). The significance of medical supply delivery, in particular, has increased significantly, especially in light of recent global events such as the COVID-19 pandemic. Drones have played a crucial role in pandemic response efforts (Koshta et al., 2021; Kumar et al., 2021; Mohsan et al., 2022), highlighting the potential for drones to interact with untrained individuals in public spaces.

Herdel et al. (2022) identified over 100 potential use cases across 16 domains where drones could interact with both trained and untrained individuals. However, given the novelty of the HDI field and the lack of expert perspectives, it remains uncertain which of these use cases will come into practice, making it challenging to focus research efforts effectively. Without thorough user-centred research on HDI in practical use cases, the potential for human error and concerns for privacy, security, and safety increases when drones interact with untrained individuals (e.g., Chang et al., 2017; Masunaga, 2019; Uchidiuno et al., 2018). A direction to handle such a challenge is to identify the use cases, which are relevant for public spaces and have a foreseeable need in the next decade, and address the related potential human factors challenges. Addressing these concerns could accelerate the acceptance and adoption of drones in society.

2.3. Design features

Literature (e.g., Arroyo et al., 2014; Cauchard et al., 2016; Yeh et al., 2017) investigated various design features of the drone, in terms of physical appearance, Human-Machine Interface (HMI), flying behaviour and sound, and provided design recommendations to support natural HDI. Design concepts (Obaid et al., 2015; Avila Soto & Funk, 2018; Szafir et al., 2015; Yeh et al., 2017) were explored for drones to effectively communicate information with humans and provide support. For example, drones may utilise audio cues for navigation (Diaz, 2017; Avila Soto & Funk, 2018) or project visual aids onto the ground to aid humans in environmental cleaning tasks (Obaid et al., 2015).

With regards to the physical appearance of a drone, anthropomorphic and zoomorphic designs have been researched in the field of HDI (Arroyo et al., 2014; Wojciechowska, Frey, Mandelblum, et al., 2019; Yeh et al., 2017) to provide humans with a perception of robots as social and interactive (Fink, 2012). The design aesthetics varied widely, as studied by Wojciechowska, Frey, Mandelblum, et al. (2019), encompassing styles from dog-like designs (Wojciechowska, Frey, Mandelblum, et al., 2019) to a cartoon face displayed on the drone (Yeh et al., 2017). There is a lack of clarity on how design choices are made regarding the significance of anthropomorphic or zoomorphic features based on the use case. For instance, the relevance of a cartoon face design for drones tasked with delivering medicines is questionable, particularly in emergencies where the primary focus is on saving human lives expeditiously rather than providing emotional engagement.

Previous research has explored various manners to communicate with recipients. For instance, flying behaviour (Cauchard et al., 2016) and propeller sound (Arroyo et al., 2014) were studied to implicitly communicate the expressions of drones. Drones can explicitly communicate intentions through HMIs with an operator and a recipient. For example, visual and sound interfaces can provide situational awareness information to the operator (Rebensky et al., 2022; Simpson et al., 2004) and visual interfaces, such as lights (Szafir et al., 2015) and displays (Herdel et al., 2021; Yeh et al., 2017), can inform the recipient about the intentions of the drone. However, it remains unclear what user-centred factors influence the design choices between different HMIs, such as lights versus displays.

The prior mentioned design concepts (e.g., physical appearance, HMIs, flying behaviour) usually aim to facilitate a natural interaction between humans and drones (e.g., Baytaş et al., 2019; Cauchard et al., 2015; 2016; Herdel et al., 2021; Obaid et al., 2020), thereby supporting the safe introduction of drones into human environments. However, the lack of standardisation with use cases has resulted in diverse design recommendations, and their potential implementation may lead to ambiguity and misinterpretation if all drones look and behave differently to communicate the same message.

2.4. Uncertainty

Uncertainty, a critical human factors challenge, "is assumed to be an important mediator in situations (interactions) with unknown outcomes (in the minds of humans)" (Windschitl & Wells, 1996, p. 343). Human interaction with robots can be such a situation, and uncertainty can significantly impact human decision-making (Lindley, 2014) and trust in automated systems (Lee & See, 2004). In order to create a natural interaction between humans and robots, it is vital to understand and respond appropriately to uncertainty (Muthugala & Jayasekara, 2016), which often arises from a lack of knowledge and information during human-robot interaction (Meissner et al., 2020). In the field of HDI, considered a sub-field to human-robot interaction, an exploratory study by Jane et al. (2017) emphasised that participants need clarity on the intentions of drones to handle feelings of uncertainty and ambiguity. Despite this need, there has been limited research on uncertainty underlining the necessity to investigate causes for uncertainty and related solution areas. A potential first step is to investigate uncertainty (and potential scenarios) from experts' perspectives and identify contributing factors, and design solutions.

3. Research gap and aim

Despite the growing body of research on HDI, current research has not yet determined the use cases that are both practically relevant and in high demand, and have not adequately addressed the challenges presented by current drone designs and the evolving human-roles in HDI. Identifying the foremost use cases and the associated human factors challenges provides scope for future research to gain insights into causal factors and develop user-centred solutions to meet the practical needs. By addressing that gap, research could contribute to the earlier and safer adoption of drones in public spaces.

Considering the numerous research groups that work on HDI around the world, expert opinions could provide valuable insights into practice-oriented challenges and expectations surrounding the research themes in the field of HDI. This study aims to identify feasible HDI use cases in the foreseeable future and the human factors challenges associated with integrating drones into public spaces. To achieve this, experts with diverse backgrounds and knowledge are consulted.

4. Method

4.1. Recruitment strategy

Previous interview studies on expert user perspectives reached acceptable results with 5 to 11 participants (e.g., Ljungblad et al., 2021; Neustaedter & Sengers, 2012; Tezza & Andujar, 2022). In this study, we wanted to focus on qualitative and in-depth data over quantity (Ljungblad et al., 2021), deciding to include a total of 11 expert participants. Experts from academia, research institutes, and industry were recruited for a semi-structured interview. Academics were invited based on their Google Scholar profiles and past publications, in line with Tabone et al. (2021). Industry and research institute experts were approached through opportunistic sampling (Ljungblad et al., 2021), LinkedIn and web pages. In addition, an advertisement was shared in the online communities of the Association of European Research Establishments in Aeronautics and with the professional network of authors' colleagues. Participating experts recommended other experts using snowball sampling techniques. In order to maintain a diverse sample, experts were recruited across the world, and only one expert was recruited from the same organisation.

For our study, recruitment of human factors experts in the field of HDI was difficult. A reason could be that the field of HDI is younger than human factors in aviation or robotics. The recruitment search was, therefore, expanded to include experts whose expertise is in the field(s) closely associated with drones (e.g., urban air mobility, aviation, human-computer interaction) and who have also worked in the field of HDI. The recruitment criteria were that the experts needed to have at least 5 years of experience in their field and at least a year of experience in HDI. Experts, who indicate that they might lack the human factors perspective, were suggested to bring a colleague with human factors experience to the interview. Both the expert and the colleague had the choice to respond during the interviews.

4.2. Participants

Eleven experts (male = 10; female = 1) were interviewed (see Table 1) and 3 out of the 11 experts brought their colleagues (male = 2; female = 1) to the interviews. Except for an expert and a colleague working on drones in contemporary art, the remaining participants work in academia, industry, and research institutes. Experts had between 8 to 25 years of experience in their field(s) of expertise ($M = 14.3$; $SD = 5.4$) and had 2 to 10 years of experience in HDI ($M = 4.2$; $SD = 2.1$). Colleagues of the experts had 1 to 10 years of experience in the fields of human factors and understanding user needs in HDI. Participants were from 8 distinct countries, primarily from Europe, including France, Germany, Poland, Spain, Slovenia, the Netherlands, and the United Kingdom, with one expert from Canada. All participants provided written consent and the study was approved by the Ethical Review Board at our university.

4.3. Interviews

Prior to the interviews, experts and colleagues were provided with background information and interview questions (see Appendix), giving them an opportunity to prepare a response. After filling out an online demographic questionnaire (i.e., gender, location, professional role, type and field of expertise, experience in years) and consent, the interviews were conducted and recorded through Microsoft Teams by the first author from January to March 2023. The interviews took between 38 and 85 minutes and were audio and video recorded.

A semi-structured interview approach was used with homogenous inputs regarding concepts covered and terminology (Tabone et al., 2021). The interview questions (see Appendix) were on 5 themes (see Figure 2) related to the field of HDI.

Themes 3, 4 and 5 mainly focused on the human-role as operator and recipient. The questions were iteratively developed after discussing with the research group members at the research institute and university, and drone pilots at the research institute.

Table 1. Expert demographics.

No.	Gender	Expertise type	Expertise field(s)	Professional role
1	Male	Research institute	Drones	Business manager
2	Male	Academia	Aeronautics, HCI[b]	Assistant professor
3	Male	Research institute	Urban air mobility	Senior researcher
4[a]	Male	Art	Contemporary dance	Developer
5	Male	Research institute	Drones	Director
6[a]	Male	Research institute	Urban air mobility	Operations and safety manager
7	Male	Academia	HCI[b]	Dean, full professor
8	Male	Research institute	Aviation, HCI[b]	Senior R&D engineer, research psychologist
9	Male	Industry	Drones, aerospace systems	Business manager
10[a]	Female	Industry	Unmanned aviation	Team lead
11	Male	Academia	HCI[b]	Associate professor

[a]represents experts who were accompanied by colleagues.
[b]represents Human-Computer Interaction.

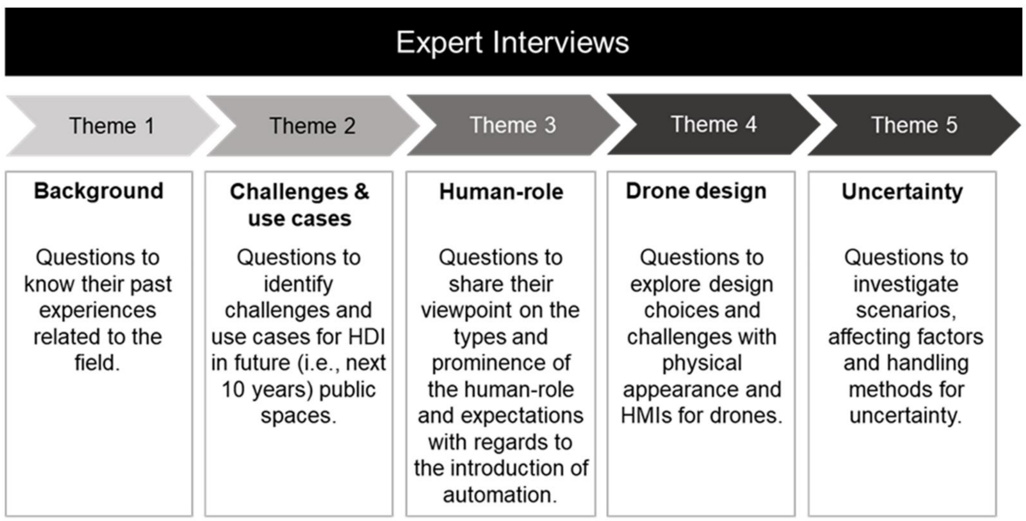

Figure 2. Description of the five themes for the semi-structured interviews with the experts.

4.4. Analysis

Interview recordings were automatically transcribed using automatic transcription software (otter.ai) and the interviewer (i.e., the first author) corrected the automatically generated text based on the recordings. Personal information (e.g., call name, organisation name) was removed from the transcriptions. Due to a technical issue, one interview was not recorded and not transcribed automatically. On request, the expert provided a written version of textual responses and then complemented with suggestions by the interviewer on grammar and sentence construction but did not add to the content. The complemented version was later reviewed and agreed upon by the interviewee.

A thematic analysis was performed to qualitatively observe, analyse and report patterns in the participant responses (Braun & Clarke, 2006). Previous research on HDI (Khan & Neustaedter, 2019; Ljungblad et al., 2021; Yao et al., 2017) deployed a thematic analysis to obtain valuable information from interview data. The first and second authors (henceforth referred to as analysts) familiarised themselves with the recordings and transcriptions. The qualitative data analysis software Nvivo was implemented to code and perform thematic analysis. The themes were data-driven and emergent. The first and second authors developed initial codes with the raw quotations as code names. Codes were assigned and sorted into sub-themes based on similarities, differences and repetitions in the codes (Ryan & Bernard, 2003). The sub-themes were then differentiated and categorised into themes (Berge et al., 2022). Figure 3 exhibits the structure of thematic analysis. The analysts exchanged codes, sub-themes, and themes and refined them with open discussions using the annotations. The transcripts were then revised and reassessed with potential new codes, sub-themes and overarching themes.

5. Results

Four themes with 14 sub-themes (see Figure 4) were identified from the thematic analysis. The main themes consisted of 1) landscape of use cases, 2) human-roles and safety concerns, 3) human factors challenges, and 4) solution areas to human factors challenges. The 4 themes are presented in the following sections and with a selection of participant quotes. Quotes from interviews are denoted with i, followed by the interview number.

5.1. Landscape of use cases

The interviewees provided their perspectives on potential use cases for drone applications in the foreseeable future (i.e., 10 years from now). Several stated that the role of drones has evolved over the past few years from military to civilian applications, which will affect the type of human interaction and the associated challenges.

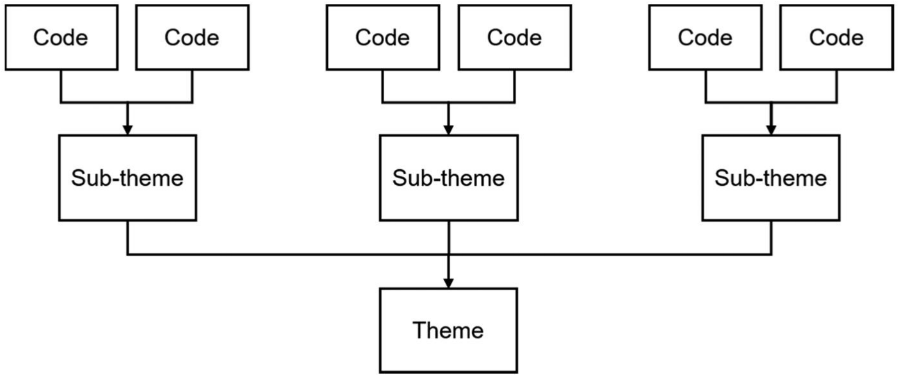

Figure 3. Relationship between code(s), sub-theme(s) and theme(s). Analysts discussed at each stage before finalising on codes, sub-themes and themes.

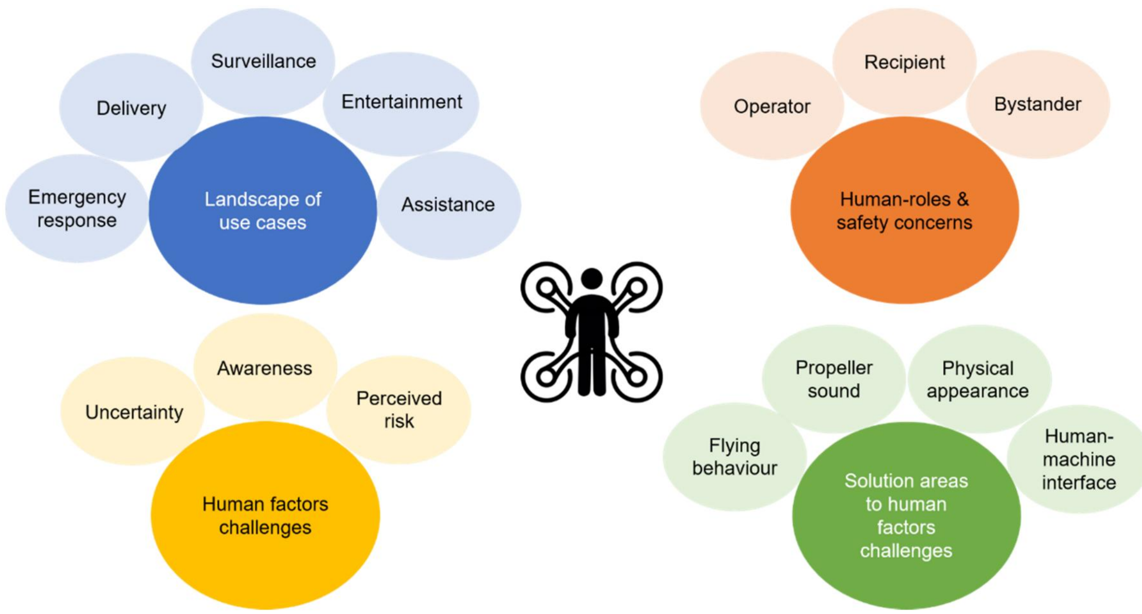

Figure 4. Themes (large ovals) and associated sub-themes (small ovals) from the thematic analysis. The themes are colour-coded: blue oval (top-left) for "landscape of use cases," orange oval (top-right) for "human roles & safety concerns," gold oval (bottom-left) for "human factors challenges," and green oval (bottom-right) for "solution areas for human factors challenges.".

Interviewees mentioned that the potential of civilian use cases depends on the acceptance from the public. Two potential use case categories, being public service and commercial, were identified for interaction with civilians. Public service use cases (e.g., search and rescue) include drones functioning for the betterment of society and not-for-profit to the drone employer. Alternatively, commercial use cases (e.g., package delivery) comprise drone services to generate profit. Due to the positive attitude of public towards public-service use cases, drones are likely to be first implemented for public service rather than commercial purposes:

> "Mostly for "good" causes (e.g., medical delivery, search and rescue)." (i2)

> "(…) it will be rather public service more than commercial." (i3)

Interviewees envisioned use cases such as emergency response, delivery, surveillance, entertainment and assistance where drones interact with humans in the near future. The use cases are described below:

5.1.1. Emergency response

Emergency response encompasses saving human lives with drone services through detecting and locating victims during accidents, search and rescue, war zones, natural disasters and fire-fighting. An example is that a drone detects road accidents, initiates ambulance dispatch and provides an emergency safety kit to the affected road user. A swarm of drones direct the public to safety during emergency evacuations in outdoor spaces.

5.1.2. Delivery

The delivery scenario includes healthcare supplies and (commercial) package delivery purposes. An increase in drone-recipient interactions is expected for medical supply delivery purposes, such as transporting medicines, organs and healthcare equipment, as the public benefit of health supply delivery outweighs safety risks.

> "We assume that in this situation (medical transport), we can allow for more (safety) risk with regards to such (medical) delivery (…)" (i3).

"I see a lot of use cases more in the public health service." (i11)

Interviewees referred to web shops that use drones to deliver commercial products and food to customers with shorter waiting times. In order to maintain operational efficiency and safety, a suggestion was to avoid a physical interaction between drone and customer:

"(With regards to physical customer-drone interaction,) I cannot imagine reliability, safety and affordability." (i3)

"We should create the system and the environment not to allow the recipient to handle the drone." (i5)

5.1.3. Surveillance

Drones interact with humans in surveillance applications such as monitoring traffic jams, concerts, and security. Drones can be used to support the police and military through crowd monitoring and crowd control during protests and criminal activities.

5.1.4. Entertainment

Drones entertain humans by becoming a part of indoor, and outdoor shows, filming, video calling and gaming. The indoor and outdoor events encompass drones as dance partners and drones as fireworks, respectively. Drones are employed for capturing pictures in social events, and filming humans for movies, media and sports. Gaming scenarios comprise racing drones and the projection of game environments on outdoor spaces for children to play.

5.1.5. Assistance

In close proximity, drones support humans in completing tasks by acting as an assistant. For instance, drones support visually impaired people through feedback (e.g., audio navigation) or bring equipment to construction workers upon request.

5.2. Human-roles and safety concerns

Interviewees indicated three types of human-roles (see Figure 5) and associated challenges with each role. Interviewees mentioned that the definition of human-role and the level of human involvement in an interaction differs with the type of use case and automation. Despite the advancements in automation and autonomous technology for drones, human-role is likely to persist and to solve constraints that might rise during the operation of drones.

"Humans will more often play the role of supervisory and policy maker to make the drones respect human defined rules and to program algorithms to solve constraints." (i2)

"I think we're not going to completely get rid of the human." (i7)

5.2.1. Operator

The role of operator was explained as someone who has full control over flying a drone. With the introduction of autonomous technology and with the increase in drone operations, interviewees predicted the shift of operator focus from directly controlling the drone to monitoring drone operations, and to perform a critical takeover when necessary.

"(…) operator might intervene if there is an emergency or so." (i1)

"We expect that as operations increase and operations get more automated, the role will shift more towards (the) supervisor." (i6)

Interviewees reflected on the control and safety challenges that arise with the shift in operator role. The change in the control paradigm for an operator lowers the need for operational skill level and allows for simple and intuitive control to perform basic tasks (e.g., input of origin and destination for package delivery), leading to "(…) much more operators who are less knowledgeable about what exactly a drone is doing" (i8). Such a change, however, "(…) present(s) piloting challenges (to unskilled operators) when things go wrong (or are unpredictable)" (i9), raising safety concerns.

5.2.2. Recipient

Interviewees highlighted the role of recipient in a close HDI space. In a delivery use case, for instance, a recipient will interact with a delivery drone while collecting the package (e.g., medicines or pizza). An argument was that two-way communication is beneficial for a recipient, meaning that not only the drone should be able to communicate with the recipient, but the recipient should also be able to convey their comfort.

"If a drone is shouting to you, but you cannot shout back, that would make me very frustrated." (i8)

"So (the) drone needs to inform me what it's doing and I need to inform it if I am okay with this." (i11)

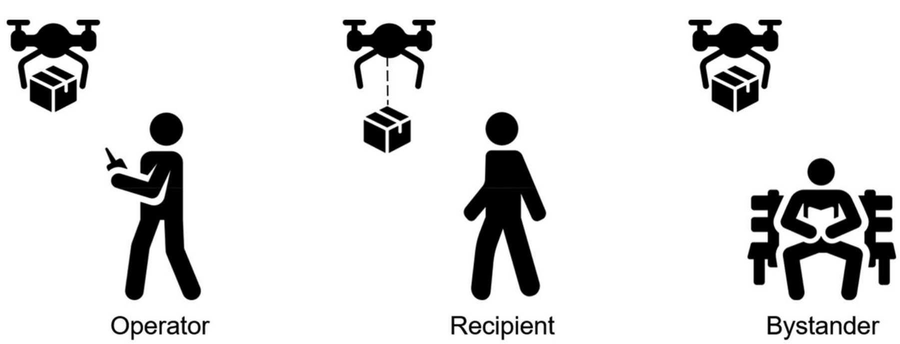

Figure 5. Three categories of the human-role in HDI in public spaces, namely: operator (actively controlling the drone), recipient (actively interacting with the drone), and bystander (in close proximity to, but not actively interacting with the drone).

Recipients are likely to have very little to no experience or training on how to interact with drones. Safety emerged as a primary concern, with minimal interaction expected between a drone and a recipient. This would be restricting recipients to perform only basic tasks:

> "(…) see them (drones) and we (recipients) will have to make sure that there is enough space (on ground) for the packages to be delivered." (i1)

> "(…) the recipients primarily should just wait and see." (i8)

Though the recipient "(…) has a role to play in affecting the behaviour of the drones" (i7), There were opposing views on whether a recipient should have any control over a drone. While some indicated that limited control (e.g., human gesturing drone to move left or right) would aid safe landings in critical situations, like crowded and emergency spaces, where situational awareness is difficult to acquire, others argued against it citing the difficulty of control transfer and the need for recipient training:

> "If something could fail, the recipient is not prepared and he doesn't know how to take control, I think it is worse." (i6)

> "I think in that case, with a crowded area and with more people, you would want to go to have some interaction with it. But these are also, I think, fairly basic interactions." (i7)

5.2.3. Bystander

Interviewees indicated the development of a passive role bystander, who is referred to as "(…) the people in the crowd" (i8) or who do not actively participate in an interaction with a drone. According to interviewees, bystanders do not necessarily control or communicate with drones but "(…) will see them fly over the houses or the gardens" (i1) and they might intend to benefit from these drones. For instance, bystanders want photos of a social gathering in their backyard from drones passing by.

> "I think, if the drones are flying by, why not? Why not try to have them for my benefit as well." (i1)

> "I wonder if I can see it on my phone. If I can go on the live stream (…)" (i9)

An argument was that bystanders are sensitive to the implications of drone capabilities towards privacy and security. For example, bystanders may view drone cameras and the possibility of drones being hijacked as threats to their privacy and security, respectively. Bystanders' curiosity provides safety challenges while landing a drone, "(…) because they (bystanders) want to see what this thing (drone) is, when they (bystanders) shouldn't, until it (drone) has settled on the ground" (i9).

5.3. Human factors challenges

Handling uncertainty in the HDI emerged as a major concern. Awareness and perceived risk were also highlighted as significant human factors challenges, which are interconnected with uncertainty.

5.3.1. Uncertainty

A major human factors challenge, reported by interviewees, was to handle (feelings of) uncertainty, explained as:

> "(…) if anything feels out of the ordinary. You lose sight of the intent or what it's going to do." (i10)

> "Whenever something happens that is in conflict with our mental model about how it should work (…)" (i11).

Interviewees mentioned uncertainty to influence workload, fear, trust, comfort, and actions: "(…) both the operator and the recipient might start making more mistakes on the procedures (…)" (i6). Interviewees hinted that "situational awareness could be the starting point" (i2) to understand uncertainty. For an operator, uncertainty could arise due to the lack of situational awareness or the lack of clarity on the takeover procedures, or risks: "(…) operator doesn't know what's going on, he doesn't know what the situation is. He doesn't know why control needs to be taken over." (i10)

Interviewees listed factors such as drone behaviour, identification, proximity, physical appearance and sound that affect uncertainty in a recipient. Uncertainty arises when the recipients are not used to drones, and when the flying behaviour of drones is not natural to predict. As mentioned by interviewees, there is uncertainty around the identification of drones and their intent in terms of, "(…) knowing what the drone purpose is, where it's coming from and who's in control of it" (i7). Proximity to the drone could make the recipient concerned about the drone's intention and could trigger questions: "What is it going to do? Is it automatic? Is it going to come and hit me?" (i9). As interviewees mentioned that physical appearance factors (e.g., size, shape and colours) of drones affect uncertainty, a challenge lies in designing drones to appear different from each other and reduce uncertainty: "If you just see a drone, it looks like every other drone kind of thing and you don't know what's going on and that black box essentially creates fear and mistrust" (i7). Interviewees suggest that if drone sounds are not within acceptable limits of noise, a feeling of uncertainty arises for the recipient and bystander:

> "You are staying in the city, and suddenly you can hear (the) sound of the drone. For sure you are uncertain, because it might fall on your head." (i5)

> "(…) drones need to maintain certain standards of noise not to bother people too much." (i6)

5.3.2. Awareness

Interviewees emphasised the importance of both operators and recipients being aware of the drone's purpose and position in the environment. Operators need situational awareness to safely operate the drone, while recipients require awareness to understand the drone's intent and safely interact.

A key challenge for operators is ensuring situational awareness during critical moments like the takeover of control (henceforth, referred to as takeover). Interviews highlighted that a takeover without awareness could endanger mission and safety. Operators should have time to grasp situational awareness of environmental conditions, like air traffic, recipients, bystanders, and collisions, before taking over. Additionally, operators need details on takeover procedures, control levels, and transition to other operators for the mission forward. Operator takeover and situational awareness could increase complexity and present challenges when operating multiple drones at the same time: "It becomes more complex and harder to grasp what's going on across the entirety of the multiple drones" (i10).

With respect to the awareness of the recipient, interviewees emphasised the need to convey information on the intentions of the drone in an interaction. Lack of awareness about the drone's intentions is explained to negatively affect the recipient experience. Interviewees stated that the recipient would like to receive information about what is their role in an interaction and purpose, status, and arrival information of the drone:

> "(…) status about what is happening." (i1)

> "The challenge will be to have people understand what they have to do." (i6)

When there are multiple recipients or bystanders, interviewees noted that there needs to be clarity regarding which recipient the drone is interacting with: "Am I the recipient or is he the recipient?" (i5)

5.3.3. Perceived risk

Perception of safety was frequently recognised as a factor affecting the interaction experience and caused by uncertainty. According to the interviewees, it is important to inform recipients about safety guarantees when interacting with drones. For instance, a recipient wants to know: "Are they (drones) going to fall on my (recipient) head?" (i9). Interviewees expected flying behaviour and the size of the drone to affect perceived safety. For instance, "(the) bigger the drone (size), (the) bigger the fear" (i5). A challenge lies with developing drones that reflect "(…) drone designs are kind of safe" (i6).

5.4. Solution areas to human factors challenges

Interviewees identified potential solutions to handle human factors challenges. HMIs were mentioned as potential solutions for both the operator and recipient roles. Intuitive designs for flying behaviour, sound and physical appearance were recommended for the recipient role.

5.4.1. Flying behaviour

Interviewees expressed that drone flight paths and patterns influence recipient perception of drones. Interviewees hinted at the relationship between flying behaviour and human factors, such as trust, uncertainty and social acceptance: "if they (drones) do make these rapid changes in movement (with flying behaviour), it becomes less intuitive (for a recipient) to guess where their drone is going, or where it's coming from and how to trust their movements. It (intuitive flying behaviour) probably also has an effect on (the) social acceptability of drones" (i10).

In order to improve intuition and reduce uncertainty for a recipient when interacting with a drone, interviewees suggested exploring the effect of different flying behaviour and designing and standardising the behaviour that are natural to predict. An interviewee recommended using flying paths with arcs, in contrast to straight line paths, in order to support a recipient to intuitively interpret drone movements: "a drone typically moves like forward and backward, instead of doing that, moving them in a curved way would perhaps enhance a certain intuition" (i10).

5.4.2. Propeller sound

While interviewees have expressed concerns about the noise generated by propellers, one interviewee suggested that conducting user research on sound design could facilitate the acceptance of drones in human environments. Sound from propellers could inform humans about the presence of drones, and that variation in sound could be used to reflect a specific use case: "I think, if a drone is totally silent, and you spot it anyway, it's quite irritating. (…) I think it's (sound variation) also condition (use case) dependent, how much noise (sound) a drone can make and what type of noise (sound) a drone should make. In an ambulance, that type of noise (sound) is needed, because the car needs to clear the way on the road in front of him." (i8).

5.4.3. Physical appearance

Interviewees agreed that the physical appearance of a drone plays a crucial role in shaping the recipient experience during an interaction: "In the end, physical appearance is something, that in general, makes people (recipients) have different feelings" (i10). Propeller guards were recommended to reduce perceived risk and to improve safety. Additionally, factors such as form, shape, size, and colour were expected by interviewees to affect social acceptance and should be considered before introducing drones in human environments:

> "(…) it's driven by the people attitude and the level of acceptance." (i3)

> "Also at a social acceptance point of view, you might use different shapes and forms for drones." (i8)

As "the physical appearance (of the drone) may affect uncertainty" (i4), interviewees expressed the need for drone design to reflect its intention and purpose based on a specific use case. Such a design has the potential to promote awareness of the intention of the drone. Interviewees drew parallels with specific vehicle designs, such as delivery trucks, ambulances, and police cars, which effectively communicate their purposes to road users. For instance, the familiar design elements (e.g., colours) associated with ambulances could be adapted for use with medical supply delivery drones.

> "It's necessary to logically relate to (…) the ambulances (…)" (i3)

> "(…) an emergency drone would look like an ambulance, it would have the same blue-red light interaction, maybe some nice stripes on there." (i10)

While discussing anthropomorphic, zoomorphic, and machine-like features, interviewees suggested that design features should align with recipient expectations for drones in specific use cases. Interviewees anticipated machine-like designs to have the least preference among recipients but were recommended for representing use case functionality (e.g., emergencies) or organisations (e.g., government). The anthropomorphic design was recommended for indoor spaces where drones act as communication devices or companions in close proximity to humans. The use of anthropomorphic designs in outdoor spaces could raise security concerns as "(…) you don't want a human to stare at you" (i2). Interviewees referred to the uncanny valley expression: "When they (drones) become very human-like, but still not (completely) human-like, we feel uneasy with these things" (i11). Designing the drone to handle uncanny valley is a challenge, as interviewees explained its negative impact on recipient comfort. The zoomorphic design was suggested to have a playful character and was recommended for outdoor spaces where the drone needs to integrate with birds while flying.

5.4.4. Human-machine interface

HMI was suggested to improve awareness and reduce uncertainty for both the operator and recipient. A recommendation was to keep the message simple and clear as "(…) the challenge (is) to develop something (HMI) that is common or usable for everyone" (i10).

Interviewees frequently mentioned visual interfaces, as a common form of HMI, to communicate information on situational awareness and takeover procedures with an operator. "They (operators) would want to know the level of confidence with which that (situational awareness) information is being provided to them" and if they are "(…) able to place their drone in the environment with as much confidence as they can" (i9). A common recommendation was to display information in order of relevance that supports an operator in making safety-oriented decisions (e.g., takeover during a malfunction) over context-oriented decisions (e.g., on flying altitude) for an autonomous drone. Operator engagement in piloting tasks was expected to increase with information on malfunctions or uncertainties about the functioning of the drone: "(…) communicating that it's (drone) not certain (with its flying behaviour, for instance), from operator perspective, is going to keep you (operator) more engaged in what it's doing. He (operator) tries to figure out why there is uncertainty" (i10).

With regards to communication with recipients, audio and visual interfaces were mentioned as the most common forms of HMI. Audio interfaces could warn the recipients when there are concerns with the landing or functioning of a drone. For instance, "(…) if there is wind affecting a drone while landing, an (audio) advice to get back a bit is valuable" (i2). Interviewees encouraged using audio advice to communicate technical malfunctions and raise awareness for recipients to take safety-driven actions: "from a recipient perspective, you're like, "okay, it's not really (in control), maybe I should take a step back" (i10).

Interviewees frequently mentioned lights and projections as forms of visual interfaces. Lights and projections were suggested for communicating different types of information with a recipient. For instance, lights could inform the recipient about the drone's purpose, such as ambulance lights, while projections on the ground could indicate where the drone intends to land. Among these two visual forms, interviewees suggested using lights (with colours) due to their familiarity with existing road technologies like traffic lights. For recipient interaction with multiple drones, interviewees recommended visual interface over audio interface as the identification is clear with visual forms such as lights on the drone:

> "If you have multiple drones giving voice commands, then it is a problem." (i6)

> "(…) you can disambiguate (with a visual interface). You just look at the drone." (i7)

Interviewees suggested another form that could be used to receive updates on the drone status is through messages sent over mobile phones. Mobile phones, according to interviewees, provide an opportunity to receive personalised messages, in terms of different forms (e.g., audio, visual), language and on use case (e.g., delivery time).

Interviewees were hesitant in suggesting the most relevant form of interface for communication with the recipient because "it depends on the situation" (I3) and each interface has its limitations. For instance, "where you have daylight, the lights (and projections) may be inefficient. In the downtown of the city, where it's noisy, voice communication can be inefficient. In some cases, communication through smartphones can be inefficient as well, because we have different devices" (I3) and "it's not natural to pull (…) phone out of my pocket" (I7). Interviewees have recommended to use redundant information with multiple forms of communication for safety:

> "I think that it will be beneficial for the safety, generally, some form of the redundancy." (i3)

> "I also think that it is good to use multiple ways of getting a message across." (i8)

Interviewees suggested that recipients will use gestures or voice as a natural form to communicate with drones. To avoid ambiguity with differences in the set of gestures or voice commands, interviewees have indicated the need for standardisation of control commands: "Is it gestures? Is it voice? I think we'll have to define a standardised set of something in one way or another" (i11). Interviewees mentioned the challenge of propeller noise interfering with voice control, suggesting that gesture control is relevant until progress is made on reducing loud propeller noise: "gesture is still the best possible scenario, because drones are loud" (i11).

The main findings from the expert interviews are illustrated in Figure 6.

6. Discussion & conclusion

This study aimed to identify introductory use cases and human factors challenges for integrating drones into public spaces in the near future. A thematic analysis of interviews produced four themes that represent the perspectives of 11 experts, the majority of whom were male and from European backgrounds, and their colleagues in the field of

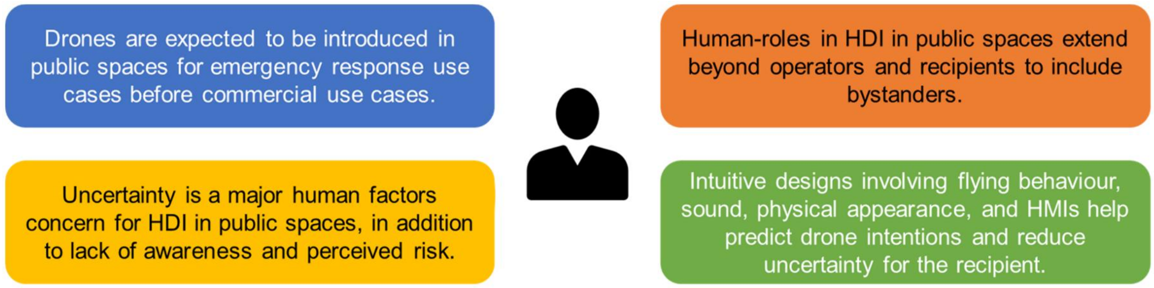

Figure 6. Key findings from the expert interviews summarised for each theme. The four rectangles are colour-coded to match the themes shown in Figure 4. The blue rectangle (top-left) represents key findings from the "landscape of use cases" theme, the gold rectangle (bottom-left) for "human roles & safety concerns," the orange rectangle (top-right) for "human factors challenges," and the green rectangle (bottom-right) for "solution areas for human factors challenges.".

HDI: landscape of use cases, human-roles and safety concerns, human factors challenges, and associated solution areas.

6.1. Future use cases

Drones that serve the public receive a positive attitude and are expected to be part of daily life in the foreseeable future. This observation confirms the survey results from Klauser & Pedrozo (2017), where the general public showed acceptance of drones in military and police use cases (i.e., public service) but not for commercial and hobby use cases. Considering operational and safety concerns, interviewees, who are primarily from European backgrounds, do not anticipate commercial delivery to be a primary use case in the near future. The growth of commercial drone deliveries, however, has exponentially increased from 6 thousand in 2018 to 874 thousand deliveries in 2022, across the world (Cornell et al., 2023). While the majority of deliveries occurred in Africa and the Asia-Pacific regions (combined share $> 69\%$), a minority of deliveries were conducted in Europe ($< 20\%$). This contrast indicates that cultural diversity may influence the selection of introductory use cases in public spaces, extending beyond the identified contributing factors such as the public's positive attitude towards the use case and safety concerns. We recommend further research to investigate additional factors, such as cultural differences and global market economics, that may influence introductory use cases across diverse cultures.

Previous HDI studies (e.g., Herdel et al., 2021; Obaid et al., 2020; Szafir et al., 2014; Wojciechowska, Frey, Sass, et al., 2019; Yeh et al., 2017) predominantly focused on indoor drone designs for social and domestic use. However, the aesthetics and flight characteristics of these indoor drones significantly differ from those designed for public spaces, such as delivery drones. Delivery drones (e.g., Wing, 2024; Zipline, 2024) operate at higher altitudes, greater speeds, and have larger dimensions compared to indoor drones examined in prior research (e.g., Herdel et al., 2021; Obaid et al., 2020; Szafir et al., 2014; Wojciechowska, Frey, Sass, et al., 2019; Yeh et al., 2017). Consequently, the difference in drone designs and user expectations for different use cases raises concerns about the applicability of interaction principles derived from domestic contexts to delivery and public service applications. HDI designers in the coming decade are recommended to focus on drone interactions with recipients in delivery and public service applications, like medical supply delivery, and explore the human needs for safer interactions in public spaces.

With the rise in drone-recipient interactions, there will be use cases in which operators are tasked with managing multiple drones simultaneously. For instance, an operator might deploy a swarm of drones to help recipients in emergency evacuations, ensuring their safe transition to outdoor spaces. In such a use case, the operator must safely operate the drones despite the increasing complexity of the task over time. Operator workload is crucial for the safety of operation, and we recommend investigating the maximum number of drones an operator can safely manage simultaneously during an emergency response.

6.2. Human-roles and human factors challenges

Our study findings highlight the three major human-roles (i.e., operator, bystander, recipient) that differ with the level of control a human (i.e., operator) has over the drone or the drone has over the actions of a human (i.e., bystander, recipient). Although previous HDI studies did not differentiate between the roles of bystander and recipient (Baytaş et al., 2019; Herdel et al., 2022; Sanfridsson et al., 2019; Tezza & Andujar, 2019), our study explicitly distinguishes between these roles and the associated challenges. Uncertainty is observed as the major concern with the human-roles.

6.2.1. Operator

Uncertainty is a concern for operators, especially when they lack situational awareness, potentially resulting in human errors and unsafety. Visual interfaces could help to mitigate uncertainty by displaying information on situational awareness and drone functionality with confidence levels. By providing information with a level of certainty, an operator has opportunities to explore the reason(s) for uncertainties and to formulate a safe approach. Providing an adequate level of information during takeover procedures becomes increasingly complex and challenging when there are multiple drones to operate simultaneously. A potential step for future research is to explore ecological interface design (Fuchs et al., 2014; Vicente & Rasmussen, 1992), where an operator understands the limitations of the work environment at different levels of complexity and uses cognitive abilities to provide creative solutions rather than to follow prescribed solutions.

6.2.2. Bystander

Previous review studies (Albeaino et al., 2022; Baytaş et al., 2019; Herdel et al., 2022; Tezza & Andujar, 2019) emphasised operator and recipient roles but not the bystander's role. While bystander-drone interaction might not occur in close spaces, unlike recipient-drone interaction, drone presence affects perception. Bystanders, who are a part of the public and passively interact with drones, have significant influence over the acceptance and adoption of drones. A significant challenge is raising awareness and handling uncertainty. As the bystander could be uncertain about the implications of drone capabilities towards privacy, security and perceived risk, future design researchers should consider bystander attitudes towards drone capabilities in their design concepts. Additionally, bystanders should be informed via mobile communication about the presence and purpose of a drone in their vicinity. Such design considerations reduce uncertainty, enhancing bystander experience and, consequently, drone acceptance. Though the inclusion of a bystander role and their attitudes is rare in the HDI design research, previous studies on noise perception of drones (e.g., Aalmoes & Sieben, 2021; Stolz & Laudien, 2022; Torija et al., 2020) provide an inspiration on exploring the attitudes of bystanders. In a study by Aalmoes and Sieben (2021), for instance, bystander attitudes forecasted noise annoyance scores during exposure to varying noise levels of a drone in a virtual environment.

6.2.3. Recipient

A significant challenge is to handle uncertainty during interactions with recipients, especially untrained individuals. Safety concerns emerge when recipients experience uncertainty about their drone interactions, affecting trust, perceived risk, fear, workload, comfort, and actions. HDI research should investigate the causes and methods to handle uncertainty. Since a lack of awareness contributes to uncertainty, interviewees suggested that supporting recipients by ensuring they are aware of the drone's intentions helps reduce uncertainty. For example, by providing task-related information (e.g., status and arrival time), indicating the landing position, and unambiguously communicating which recipient the drone is interacting with when multiple recipients or drones are involved. Moreover, flying behaviour, physical appearance, propeller sound, and HMIs can assist recipients in predicting the intentions of the drone. Along similar lines, research on automated vehicle-pedestrian interaction showed that vehicle behaviour, appearance and external HMI help pedestrians to predict vehicle intention and affect willingness to cross the road (Dey et al., 2021; Oudshoorn et al., 2021).

In order to achieve flying behaviour that is natural for a recipient to interpret the drone's approach and landing, an interviewee recommended implementing flying paths that have the form of an arc rather than a straight line. An explanation is that arc paths are more legible than straight line paths, similar to the observation in Szafir et al. (2014). Other behavioural solutions explored in the literature on social drones include speed, height and distance of the drone from the recipient (Cauchard et al., 2016; Wojciechowska, Frey, Sass, et al., 2019; Yeh et al., 2017). The validity of these solutions for public service drones is yet unknown considering the difference in purpose, flying speeds and altitudes. We recommend investigating how different characteristics of flying patterns, speed and height influence the ability to predict where the public service drone will land.

Future research directions include the physical appearance and propeller sound of a drone as a means to build awareness of the drone's intentions among the recipients. For instance, ambulances could provide design inspiration for medical supply delivery drones in terms of colour and sound. Previous research (see Baytaş et al., (2019); Obaid et al., (2020) for reviews) explored the design space for social and domestic drones but lacked medical supply delivery drones, among others. Researchers should explore recipient expectations, examine the impact of appearance on drone perception and inferred intentions, and iteratively design concepts through user experience studies.

Besides the flying behaviour, sound and physical appearance of a drone, visual and audio interfaces are recommended to foster awareness of the drone's intentions. While physical appearance could be used to communicate broad and static information on the purpose of the drone, interfaces could complement with specific and dynamic information (e.g., advice on landing position). Along similar lines, visual and audio interfaces were used to persuade recipients to clean the environment in a study by Obaid et al. (2015). Interviewees were divided in recommending the "right interface" as it depends on the message and limitations of each design. Lights and voice commands, for instance, could be used to warn recipients about a malfunction but are inefficient in the sunlight and in noisy environments, respectively. It is unclear yet what information, beyond purpose, a recipient expects and needs from a drone during an interaction, and how this information is use case dependent. It is recommended to investigate the recipient's needs and the contributing factors for information needs in use cases, and subsequently develop and test interfaces to convey the necessary information. For example, recipients may want to know what the drone is carrying and where the package is dropped in a delivery scenario, but they may be interested in the drone's "emotional state" when interacting with a social drone.

Similar to the findings in Cauchard et al. (2015), some interviewees encouraged the idea of recipients controlling autonomous drones, for instance, using gestures and voice commands. Others argued against the idea by referring to the safety challenge that emerges with untrained recipients and control transfer. Empirical studies are necessary to determine whether an untrained recipient requires control and to what extent, as well as to identify the driving factors within a given use case. Subsequently, research should delve into human-machine teaming solutions that benefit both the recipient and the operator in completing a task. For example, a recipient could have limited access, such as the ability to initiate an emergency stop when the drone gets too close for comfort. Alternatively, a recipient may have control at a strategic level, such as indicating a safe landing spot, but not at a granular control level, such as specifying left or right directions.

Beyond the proposed solutions for human factors challenges, future research should explore aerial manipulation techniques to assist recipients and support natural HDI. These techniques, such as cables, robotic arms, and haptics, have been utilised in diverse fields including product delivery (Wing, 2024; Zipline, 2024), construction (Lindsey et al., 2012), and Virtual Reality (VR) environments (Fedoseev et al., 2022). For instance, delivery drones by Wing and Zipline use cables to deliver packages to recipients on the ground, while in VR environments, drone swarms employ tactile actuators to provide haptic feedback to recipients' fingertips, simulating interactions with virtual objects (Fedoseev et al., 2022). The physical manipulation of objects and users poses significant implications for HDI in public spaces. The close proximity required for these operations can be intimidating or frightening due to the novelty of aerial manipulation among the public. Drones may need to approach very closely to deliver or manipulate objects and people, introducing uncertainty, perceived risk, and safety challenges that must be addressed to support safe and natural HDI. As an initial step, we recommend investigating the impact of different aerial manipulation techniques on recipients' feelings of uncertainty across various use cases in public spaces.

6.3. Considerations

The authors acknowledge that HDI is a broad research field and the type of human interaction could differ with the types of drones (e.g., design, size), the behaviour of the group, familiarity with drones, human-roles, the physical appearance, the exact circumstances, among others, thereby raising additional questions and challenges. Though we made attempts to include a few of the above factors in our study, there is a need for complementary future studies to investigate additional challenges, including the influence of diverse shapes and sizes of drones in public spaces on user experience and human factors.

In the recruitment strategy, the authors made consistent and thorough attempts to engage with and recruit experts from diverse demographics through various channels (e.g., social media advertisements, emails, snowball sampling) over a span of 5 months. Although we reached a degree of saturation in results (e.g., similar themes across the sample) with 11 interviews, our study sample is skewed towards the male population and most of the interviewees are from European countries. The study results primarily apply to European context, raising the need for future studies that include perspectives of experts from different gender groups and countries.

Another limitation of our expert interview study is the potential bias among experts towards specific use cases based on their expertise. Our study does not aim to replace user-centred studies but rather complement them. While we supplemented our findings with insights from the user-centred design literature, interviewing potential users from the general public during the current times may result in speculative responses because of their limited experience with drones in public spaces.

7. Conclusion

The present study interviews 11 experts from varied backgrounds including academia, industry, and research institutes to identify relevant use cases and major human factors challenges in HDI. This identification is crucial for addressing priority concerns and expediting the integration of drones into society to leverage the benefits of drone technology. The study underscores the importance of prioritising human factors research for public use cases, such as emergency response and delivery scenarios, over social and domestic applications in the near future. With the rising use cases and the automation technology, there are mainly three different human-roles, namely operator, recipient and bystander. The study distinctly outlines the roles of the general public as bystanders and recipients, elucidating their specific challenges and providing a basis for future design research. Handling uncertainty is regarded as a major human factors challenge stemming from a lack of awareness of the intentions of the drone, particularly impacting (untrained) recipients. In order to handle uncertainty for recipients, designers are suggested to develop specific drone behaviour, physical appearance and drone interfaces that are easy to interpret and help predict the drone's intention.

Note

1. Drones, in this study, are referred to flying robots or small unmanned aerial vehicles.

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Appendix

Some prior information to support the questions

Human-Drone Interaction (HDI) includes human(s) interacting with drone(s) in different roles (e.g., operator, recipient). The drones, referred here, are small unmanned aircraft vehicles or flying robots.

Terminology used in this study

1. Anthropomorphic design: A system design inspired from human characteristics (e.g., eyes, speech, mouth).
2. Autonomous drone: A drone that can perform the tasks on its own without the need for human assistance or intervention.
3. Communication interfaces: User interfaces used to communicate the relevant information (e.g., maps, drone intent, feedback) from the agent (e.g., drone) to the recipient.
4. Dual control: An agent (e.g., drone) having two sets of controls. For instance one set of control is with the operator and the other with the recipient.
5. External Human-Machine Interface (eHMI): Communication devices, in the form of display, sound, haptics, among others, attached to a drone to communicate with surrounding recipients. For instance, drones broadcast health announcements via voice message to control gatherings during COVID-19 in Shanghai.
6. High-level control: Control Inputs for an agent at a tactical level (e.g., move forward, left or backward) or strategic level (e.g., location coordinates, departure time).
7. Human-machine interface (HMI): A user interface that connects a person to a machine, agent (e.g., drone) or device.
8. Recipient: An individual who passively interacts and aims to benefit from the interaction with the drone but may not necessarily control a drone.
9. Operator: An individual who has the primary control over the drone and uses an interface (e.g., joystick controller) to control the drone remotely and to perform a task (e.g., hobby flying).
10. Zoomorphic design: A system design inspired from animal characteristics (e.g., wings, size, body structure).

Interview questions

This interview explores experts' opinion and vision on the interaction between humans and autonomous drones from a human factors' perspective. First, the questions focus on your background with drones. Next, expectations and challenges with the introduction of drones in the close proximity of humans are discussed. Next, evolution of human-role and their interaction needs are explored in HDI. Following this are the questions related to challenges and information needs associated with the design of the drone and its HMIs. The interview concludes with exploration on methods to measure and handle uncertainty in HDI.

Theme 1: Background

1. What exactly do you do/research with the drone?
2. How does a human (e.g., operator or recipient) interact with drones in your work? What are the challenges?

Theme 2: Challenges and use cases in HDI

1. Do you think there will be hindrances in the introduction of drones in public spaces? If yes, what are they? If not, motivate?
2. Considering the next 10 years of the drone market, what are some use cases in which you anticipate drones to interact with humans in proximity?
3. Do you think interactions between multiple drones and humans will happen in human environments? What are some advantages and challenges?

Theme 3: Human-role

1. How do you expect the human-role to evolve with the introduction of autonomous drones?
2. Can you give some examples related to a task where a human would like to have some degree of control? What could determine this degree of control?
3. Think of a medical emergency scenario, where an operator controls a drone to deliver medical supplies to a recipient. What do you think if the recipient has a high-level control (e.g., gestures, voice) to help the drone? Is dual-control beneficial and how does it compare to an autonomous drone?
4. In what scenarios do you expect an operator to face difficulty when taking over control? Why?
5. In what scenarios do you expect a recipient to have difficulty in a close interaction? Why?

Theme 4: Drone design

1. What is your preference between anthropo-/zoomorphic and non-anthropo-/zoomorphic drone design? Why?
2. Following are questions on communication interfaces for autonomous drones:
   a. Can you name three major challenges to develop an intuitive HMI for communication with: (a) operator and (b) recipient
   b. What information about the environment, including recipient, could be helpful for an operator to take-over control?
   c. What kind of information is essential for a recipient to comfortably interact with a drone? Why?
   d. What would be the ideal way(s) for a drone to communicate with a recipient? Why?
   e. Can it also be applied to multiple drones or recipients?

Theme 5: Uncertainty in HDI

Uncertainty could be explained as the state of being uncertain or unsure. Humans and drones may contribute to uncertainty in the HDI. For instance, an operator is perhaps uncertain about the recipient's actions while controlling a drone to deliver medical supplies. Another example, varying wind patterns may lead to uncertainty in drone flight behaviour, possibly affecting recipient's interpretation of drone movements.

1. Can you describe scenarios where an operator and/or a recipient may feel uncertain?
2. Do you feel that noise or variation in drone movements could affect the uncertainty feeling? Why?
3. What could be other contributing factors (mention three)? And as an initial effort, how do you suggest handling it?
4. Can you suggest method(s) to measure uncertainty?
5. Do you feel that a drone communicating its uncertainty is beneficial?
6. Do you think the drone's physical features could affect the recipient's feeling of uncertainty and their actions? Why?
7. Do you think an eHMI has the potential to reduce the recipient's feeling of uncertainty? How does it translate to multiple drones and recipients?

Do you have any suggestions or recommendations on the research gaps that you would like the future research to explore?