Human-Multi-Drone Interaction in Search and Rescue Systems under High Cognitive Workload

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Abstract

Unmanned Aerial Vehicles (UAV), often referred to as drones, have seen increased use in search and rescue (SAR) missions. Traditionally, these missions involve manual control of each drone for aerial surveillance. As UAV autonomy progresses, the next phase in drone technology consists of a shift to autonomous collaborative multi-drone operations, where drones function collectively in swarms. A significant challenge lies in designing user interfaces that can effectively support UAV pilots in their mission without an overload of information from each drone and of their surroundings.

This thesis evaluates important human factors, such as situational awareness (SA) and cognitive workload, within complex search and rescue scenarios, with the goal of increasing trust in multi-drone systems through the design and testing of various components. Conducting these user studies aims to generate insights for the future design of multi-drone systems.

Two prototypes were developed with a multi-drone user interface, and simulated a stressful search and rescue mission with high cognitive workload. In the second prototype, a heatmap guided UAV pilots based on the lost person model. The prototypes were tested in a conducted user study with experienced UAV pilots in different SAR organizations across Sweden.

The results showed variability in SA while monitoring drone swarms, depending on user interface components and SA levels. The prototypes caused significant cognitive workload, slightly reduced in the heatmap-equipped prototype. Furthermore, there was a marginal increase in trust observed in the prototype with the heatmap. Notably, a lack of manual control raised challenges for the majority of participants and many desired features were suggested by participants. These early expert insights can serve as a starting point for future development of multi-drone systems.

Keywords

Unmanned aerial vehicle ● Human-drone interaction ● Cognitive workload ● Trust ● Search & Rescue ● Drone swarm ● Situational awareness ● Multi-drone systems
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List of Abbreviations

CI  Confidence Interval
IPP  Initial Planning Point
LKP  Last Known Point
MD  Mean Difference
NASA-TLX NASA Task Load Index
POA  Probability of Area
SA  Situation Awareness
SAGAT Situational Awareness Global Assessment Technique
SAR  Search and Rescue
SD  Standard Deviation
SEQ  Single Ease Question
UAV  Unmanned Aerial Vehicle
UI  User Interface
VAS  Visual Analogue Scale
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1 Introduction

Searching for missing people is a challenging task, especially with critical demands of the mission in tough surroundings. Robots and drones, specifically unmanned aerial vehicles (UAV), have increasingly taken on these tasks. While UAVs have proven to be effective in supporting search and rescue (SAR) missions, often controlled manually for each drone, there is now a growing interest in multi-drone systems. These systems involve drones collaborating as a swarm with higher levels of autonomy to enable faster and more complex SAR missions. The development of such systems are predicted to be valuable for the police and rescue organizations. However, the shift from supervising and monitoring single drone to multi-drone systems presents several challenges.

Multi-drone systems should display a simple and clear user interface (UI) to avoid confusion or misinformation, as this could harmfully impact the SAR mission and the trust towards the system. It is essential that the UI can visualize data for easy viewing for monitoring the drone swarms. However, even with an intuitive UI, the stressful situations that often occur during a SAR mission may still affect a human’s decision-making and situational awareness (SA), leading to increased cognitive workload. Therefore, incorporating data visualization elements guiding the UAV pilots in multi-drone systems can support SA, reduce human errors, and decrease the cognitive workload. Best design practices for multi-drone systems remain active research fields and have not been fully explored within search and rescue missions.

This master’s thesis is performed in collaboration with researchers from Aalborg University in Denmark, who are partners in the research project HERD. The HERD project aims to comprehend the complexities of multi-robot collaboration, while designing and evaluating technological solutions that enable end-users to control and engage autonomous multi-robot systems. Within the context of HERD, UI prototypes for multi-drone systems are being developed to address the needs of both search and rescue missions and agriculture farming.

Figure 1: A drone manufactured by Robotto, an AI company and industrial partner of the HERD project, is used for search and rescue missions.

https://herdproject.dk/ [Accessed 2024-01-05]
1.1 Problem Definition

This thesis addresses design and implementation of proof-of-concept for multi-drone systems used in SAR missions by UAV pilots. Additionally, this thesis will explore how the stressful nature of SAR missions can impact the pilots’ decision-making and situational awareness (SA). This study also aims to examine the level of SA in the multi-drone system and how incorporation of different design components to enhance decision-making, mitigate human errors, and improve usability during critical rescue missions. One particular aspect which will be emphasized in this thesis is the significance of building trust in human-multi-drone interaction through data visualization related to the needs of the SAR mission. Establishing trust between UAV pilots and the autonomous multi-drone systems is vital for effective collaboration and ensuring successful SAR missions.

1.2 Aims & Objectives

The following aims and objectives are strived to be answered in this thesis:

A1 Identify how trust can be increased through a multi-drone system under high cognitive workload.
   
O1 Identify appropriate human factors affects UAV pilots.
O2 Define suitable drone requirements and components supporting to the human factors identified in O1.
O3 Develop a limited proof-of-concept multi-drone system with a simulated search & rescue mission.

A2 Evaluate how the human-multi-drone interaction is practically performed in a simulated search and rescue multi-drone system.
   
O1 Identify appropriate evaluation metrics to measure appropriate human factors.
O2 Combine and evaluate literature and experimental results.
1.3 Research Questions

This thesis begins with Chapter 1, which gives an introduction to the area of the thesis together with a problem definition. This chapter also presents the aims and their corresponding objectives for this thesis.

Chapter 3 continues with a literature review, to explore background and investigate what contributions are available in the specific research areas. Within this Chapter, it investigates drones’ collaborative potential in SAR missions (section 3.1.3), presenting their ability to function as a swarm. However, it underscores significant gaps (section 3.3.1) in integrating drone swarms into needs and practices of UAV pilots, emphasizing the importance for user-friendly interfaces.

This Chapter also identifies challenges linked to situational awareness in human-multi-drone interaction, particularly concerning cognitive workload and trust. Subsection 3.6.1 suggests addressing these challenges by integrating data visualization elements related to lost person model in search and rescue into drone features to enhance effective collaboration.

Chapter 3.7 identifies key factors and information gaps within existing SAR drone applications and research articles. Particular attention is paid to factors relevant to multi-drone solutions in real-world SAR contexts.

Based on the aims specified in section 1.2, the following research questions along with their corresponding hypotheses are strived to be answered.

RQ1 Determine whether the system messages are visible to the multi-drone pilot in a search and rescue system, promoting situational awareness?

H1 Visible system messages enhance situational awareness in search and rescue multi-drone system.

RQ2 Determine whether a heatmap, based on the lost person model, increases trust in the multi-drone pilot during high-cognitive-workload monitoring of a search and rescue system?

H2 A heatmap using the lost person model increases trust in multi-drone pilots during high-cognitive-workload monitoring in a search and rescue system.

This will be emphasized for the rest of the thesis.
2 Methods and Approach

This chapter presents the methodology to be used to developing, testing, and evaluating the solution and sets the scope of the thesis work. A collaboration with an external research group is utilized to serve as an example on how the solution can be applied in a real-world context.

2.1 Collaborative HERD Research Project

In order to complete the development of a realistic multi-drone system, including a user interface along with a real-world search and rescue scenario, the HERD research project is collaborating in this thesis.

2.1.1 The HERD project: Human and Robot Swarm Interaction

HERD is a DIREC project (Digital Research Centre Denmark) involving a group of researches and two private robot companies in Denmark. The project, which began in November 2021, is scheduled to finish by July 2025. Its primary goal of the project is to comprehend challenges within multi-robot collaboration and advance robot technology, enabling drones and robots to collaborate effectively in swarms.

The project also aims to create and evaluate user interfaces for efficient engagement and control of autonomous multi-robot systems [1]. The investigation focuses on exploring how robots can autonomously coordinate their actions and adjust to specific surroundings while working together as a swarm to accomplish assigned tasks. This research aims to facilitate the development of the next phase of collaboration between humans and swarms, enhancing their cooperative capabilities for the future. Figure 2 shows the robotic platforms employed by HERD’s industrial partners.

![Robotic platforms](image)

Figure 2: The robotic platforms utilized by industrial collaborators of HERD, serve both agriculture and search rescue domains [1].

[1] Johanna Ahlskog

References:

- https://robotto.ai/ Accessed 2023-12-20
- https://agrointelli.com/ Accessed 2023-12-20
HERD is crafting specific use cases based on the domain knowledge and robotic hardware provided by its industrial collaborators. The two distinct use cases revolve around agriculture and search rescue applications\(^5\). They offer unique opportunities to explore swarm interactions in different scenarios. The agricultural context allows for careful planning, while search rescue involving drones operates within dynamic and rapidly evolving domains.

These two application domains share common traits involving time-sensitive missions conducted across diverse geographical regions, strategized by domain experts\(^1\). Both domains encompass inherent stochastic elements, such as unpredictable weather conditions. The robots and drones in both domains are mobile, equipped with extensive onboard sensor systems and processing capabilities, requiring collaboration among humans and other robots/drones. However, in contrast to the agricultural setting, the operational environment for SAR drones is the airspace, focusing on tumultuous and rapidly evolving emergencies as illustrated in Figure 3. In scenarios demanding extensive area coverage and operations within complex terrain, a single drone’s capabilities fall short.

Figure 3: Drones operating in swarms, with their improved vision, serve as crucial tools for future SAR missions. To effectively aid in rescue searches, drone swarms need autonomous capabilities and rapid responsiveness.\(^6\)

To address the SAR use case, HERD has developed a multi-drone prototype.

2.1.2 Overview of the HERD Multi-Drone Prototype

The HERD team has developed a SAR prototype capable of managing multiple drones in outdoor settings, providing a more realistic testing environment compared to controlled laboratory studies. This drone control prototype consists of three key components: a drone controller, a server, and a web application\(^2\). The web application’s design focuses on facilitating continuous interaction between drones and the pilot, offering the added benefit of platform independence. For connectivity, the server can be hosted on a local computer, serving as the bridge between web clients and intelligent controllers. As this is the initial prototype for the project, there is potential for many improvements to be made.

This prototype is built on specific SAR requirements that might have wider relevance and application across various other drone swarm implementations. Within the HERD SAR multi-drone prototype, the implemented characteristics include the following:

- The main goal to cut SAR operation time by enabling efficient management of multiple autonomous drones. Success in SAR depends on rapid responses as survival rates decrease with time, highlighting the need for resource-wise utilization.

- In SAR operations, search strategies vary based on mission specifics, including the lost person’s condition, terrain, and pilot preferences. User-friendly tools are crucial for pilots to easily adapt autonomous UAV strategies, whether collectively, individually, or by manual control of a single UAV.

- The UI should facilitate efficient control of the multi-drone system, adapting to changing SAR conditions. The current prototype enables users to view active drones on a map and assign several drones to a common destination. This map displays the drones’ current and projected flight paths.

- Given the limited flight time of UAVs, typically lasting only a few tens of minutes, an autonomous multi-drone system needs to consider this constraint into pre-operation and on-the-fly planning. As batteries unavoidably drain and need replacement or recharging, it’s crucial for the UAV pilot to have clear visibility into the battery status.

- This prototype will employ dynamic multi-drone planning and coordination algorithms resilient to environmental shifts and varying numbers of participating UAVs during the search. These algorithms aim to uphold situational awareness of the UAV pilot.

- This prototype includes a menu to provide current drone information and their status.

- This prototype includes a menu to provide information about current flight paths and previous flight paths.

- This prototype receives real-time video data from multiple drones at the same time. However, the processing and presentation design for camera feeds is still in development, aiming to improve the situational awareness of the drones’ behavior as HERD continues its improvements.

- HERD’s recent discoveries highlight the need for integrating a degree of UAV autonomy beyond search functions to ensure safe operations in real-world SAR environments. With other independent entities like helicopters and search personnel within the search area, this implementation is vital for the prototype’s functionality.
This project underscores the crucial role of the UAV pilot in integrating with the drone swarms within the multi-drone system as a unified unit, tasked with establishing mission priorities and constraints. At the same time, the UAV pilot must have the capability to step in and take control of a single robot or a specific subset of robots as required. For instance, in emergency response situations, a responder might need to take charge of a drone to monitor personnel close to a search area. This introduces a new set of challenges distinct from the traditional and old paradigm, where there exists a direct one-to-one correspondence between UAV pilot and robot, as discussed in Chapter 2.

Figures 4 and 5 illustrate HERD’s ongoing iterative work on developing the drone swarm prototype. These figures also illustrate how some of HERD’s SAR requirements are integrated into the prototype, such as the map view of the drone swarm together with the drone side menu with the battery status visibility.

Figure 4: The initial HERD prototype with the drone swarm map and drone side menu.

Figure 5: The evolved HERD prototype, after a couple of design iterations, presenting the drone swarm map and drone side menu.
2.2 Methodology to Develop, Test, and Evaluate the Solution

The development of the multi-drone system will follow an agile approach, utilizing the principles of the Double Diamond model. The Double Diamond is a graphical representation of the design process, using two diamond shapes to illustrate the four main phases aimed at designing the right solution effectively. The phases of this framework are: Discovery, Definition, Design, and Delivery.

Table 1 provides comprehensive explanations of the methods in each phase of this thesis work. This design framework aligns well with the project’s emphasis on user-centered requirements and iterative development, given the system’s goal of serving as a proof-of-concept implementation.

Table 1: This thesis is using the Double Diamond design model with its four phases, each using particular methods.

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<tr>
<th>Phases</th>
<th>Definition</th>
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<tr>
<td>Discover</td>
<td>Conducting background research on end-users impacted by the issues, to gain valuable insights.</td>
<td>1) Literature Review 2) Previous work in the area and the characteristics of search and rescue systems.</td>
</tr>
<tr>
<td>Define</td>
<td>Use the insights gathered from the previous phase to refining the specific problem through research questions.</td>
<td>1) Define proof-of-concept requirements</td>
</tr>
<tr>
<td>Design</td>
<td>Iterate on various potential solutions for the defined research questions.</td>
<td>1) Prototyping 2) Implementing solution</td>
</tr>
<tr>
<td>Deliver</td>
<td>Test solutions, gather feedback, and refine the solutions based on the results.</td>
<td>1) User Study 2) Evaluation of test results</td>
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In the Discover phase, literature and related work reviews will be performed. These findings will define the product requirements, serving as guidelines to support the design of the UI.

Designing the multi-system will begin with a prototyping phase, followed by the implementation of the software. The key components of the system include the user interface, drone swarm algorithm, and situational data, which together simulate a realistic search and rescue mission. An initial prototype structure, incorporating familiar cues previously tested by emergency services, will be drawn from a collaborative research project. A pilot study will be conducted to validate the methodology and technology before testing on real end-users.

To test this type of system in the delivery phase, a mixed-method experimental study with a participatory mindset will be used, highlighting early insights from experts on what features should be included and what they desire. A user study will be conducted involving two distinct scenarios. Firstly, a scenario involving a significant volume of situational data will be integrated into the multi-drone system while the user operates it. Secondly, a scenario will be implemented, introducing a heatmap on the map view based on the lost person model within the prototype.

7 https://www.designcouncil.org.uk/our-resources/the-double-diamond/history-of-the-double-diamond/ Accessed 2023-10-22
To evaluate the system, a comparison will be made to determine the impact of the heatmap on user experience. These two distinct scenarios aim to evaluate how end-users interact with a multi-drone system and to highlight potential benefits and drawbacks of incorporating the heatmap. Differences between these two prototypes will be explored, focusing on human factors such as trust, situational awareness, cognitive workload, and the overall usability advantages and disadvantages of the system in a real-world context.

2.3 User Study Research Methods

To answer the thesis’s research questions, a user study will be carried out. The research methods which will be utilized in this user study are summarized in Table 2. The following subsections provide a detailed explanation of each research method.

Table 2: A summary of the research methods used to answer the research questions of the thesis, including their goals and descriptions.

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<td>Measure perceived stress level</td>
<td>RQ1, RQ2</td>
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<td>Situation Awareness</td>
<td>Quantitive situational awareness parameter</td>
<td>RQ1</td>
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<td>Global Assessment</td>
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<td></td>
<td>Technique</td>
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<td>RM3</td>
<td>NASA Task Load Index</td>
<td>Quantitive cognitive workload parameter</td>
<td>RQ2</td>
</tr>
<tr>
<td>RM4</td>
<td>Emocards</td>
<td>Measure perceived usability</td>
<td>RQ1, RQ2</td>
</tr>
<tr>
<td>RM5</td>
<td>Single Ease Question</td>
<td>Measure perceived usability</td>
<td>RQ1, RQ2</td>
</tr>
<tr>
<td>RM6</td>
<td>Human-Computer Trust</td>
<td>Quantitive trust parameter</td>
<td>RQ2</td>
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<td>Qualitative trust, and usability parameters</td>
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2.3.1 Visual Analogue Scale (RM1)

Visual Analog Scale (VAS) is a measurement tool often used in research and clinical environments to evaluate subjective characteristics or attitudes that cannot be directly measured. It is typically illustrated as a straight line around 10 centimeters, either drawn on paper or displayed on a computer screen. The line represents a spectrum of a particular emotion, such as stress. In this user study, a VAS will be used before introducing the prototypes, to evaluate participants’ perceived stress states. Participants will be asked to express their current stress state using a 1-10 point Likert scale, where 1 equals relaxed feeling, and 10 equals a strong feeling of extreme stress. This is done to measure the current stress level of the participants to see if it affects their results of the user study, especially regarding cognitive workload and situational awareness.
2.3.2 Situation Awareness Global Assessment Technique (RM2)

In this user study, situation awareness (SA) will be evaluated using the Situation Awareness Global Assessment Technique (SAGAT) [4]. It is a methodology often used to evaluate and measure a pilot’s SA, particularly in high-stress and complex environments, such as during flight operations. SAGAT offers a real-time evaluation of the pilot’s SA of the system, categorizing SA into three different levels: perception, comprehension, and projection. Each level of SA is analyzed by a set of questions, each with a predetermined correct answer based on actual events in the system [5]. This method allows a direct and unbiased evaluation of SA. To ensure accuracy, SAGAT questions are presented during simulation pauses with deactivated displays, known as the freeze technique. This enables participants to recall only what they authentically perceived and remembered from the most recent situation.

2.3.3 NASA Task Load Index (RM3)

NASA TLX Task Load Index [8] plays a crucial role for evaluating cognitive workloads, particularly in complex domains like aviation. Within this user study, the method will be utilized to measure the cognitive workload associated with using the prototype under high-stress conditions. By having participants rate and evaluate various cognitive demands, the tool computes a comprehensive weighted workload. This approach helps pinpoint the type of the workload and provided evidence that participants were operated under intense cognitive demands [6]. This tool covers parameters such as Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Performance (P), Effort (E), and Frustration (F).

2.3.4 Emocards (RM4)

![Emocards](https://humansystems.arc.nasa.gov/groups/TLX/)  
Accessed 2023-11-12

Figure 6: Male and female emo cards that show eight different emotional expressions, which are measured based on the two dimensions of pleasantness and arousal [7].
METHODS AND APPROACH

Figure 6 illustrates emocards, which include 16 cartoon faces representing eight distinct emotions, with versions for both female and male representations of each [7]. These emotions are grouped based on their “arousal” and “pleasantness”, forming a model where highly arousing and excited emotions such as “annoyed” are positioned above, while calm emotions like “bored” are situated at the bottom. Unpleasant emotions are on the left, while pleasant emotions are on the right.

These cards serve as a tool for individuals to express their emotional reactions during discussions, aiding in objectively express feelings about a situation or a product 9. Participants select cards that closely align with their emotions, initiating discussions among designers, researchers, and participants regarding these reactions.

2.3.5 Single Ease Question (RM5)

Single Ease Question (SEQ) method functions as a tool to assess the ease of performing a particular task [8]. The participants will be asked after the completion of every task for each prototype, to rate the difficulty of the task on a 7-step Likert scale from “Very easy” to “Very difficult”. These SEQ results not only measure the ease of these tasks but also offer valuable data for future experiments and investigations.

2.3.6 Human Computer Trust Scales (RM6)

The human computer trust scale is a tool specialized in assessing trust in human-computer interactions 10. It evaluates both cognitive and emotional dimensions of trust, with the emotional aspects playing a significant role in determining trustworthiness. It’s a well-developed instrument tested by various researchers. In this user study, two different variations of the human computer trust scale will be utilized.

The first scale, based on the work of Jensen et al. [9], measures trust aspects related to the system’s ability, integrity, and benevolence. Ability refers to the system’s competencies or skills within a specific domain (in this case, SAR missions). Integrity relates to the system’s acceptance of a set of principles, and benevolence measures the extent to which the system acts in the best interest of the trustor, i.e., the human. This scale will be used for both drone prototypes, and each of these three aspects has four statements, each evaluated on a 7-point Likert scale.

The second scale, developed by Gulati et al. [10], will be exclusively used to evaluate the second drone prototype with its heatmap as an extension of the first scale explained above. With a focus on the drone prototype itself, specifically the heatmap, this scale includes only four questions, maintaining a similar Likert scale rating from 1 to 7.

More detailed information about the statements used in both scales for the user study can be found in Appendix B.1.

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9 https://experienceresearchsociety.org/ux-methods/emocards/ Accessed 2023-11-15

Johanna Ahluskog
2.3.7 Semi-structured Interviews (RM7)

For a deeper understanding of participants’ experiences with the prototypes, semi-structured interviews \(^\text{11}\) will be conducted after each prototype. This approach allows flexibility, enabling the interviewer to ask follow-up questions and explore unexpected topics that emerge during the interviews. Initially, the interviews will be conducted in Swedish and later translated into English for this thesis.

The analysis of the results will involve thematic analysis \(^\text{11}\), chosen for its user-friendliness and ability to provide a comprehensive view of the data without losing any details. The primary tool for qualitative analysis will be Voyant Tools \(^\text{12}\), a web-based application. This tool is essential for performing thematic analysis on the interview transcriptions, aiding in analyzing and extracting keywords within their context, and identifying relationships between these words. Additionally, a comprehensive analysis will be conducted based on the user responses, focusing on each interview question.

By using the solution design discussed in this Chapter, together with a real-world example of a collaborative research project, the prototype implementations can take place.

\(^{11}\) https://experienceresearchsociety.org/ux-methods/semi-structured-experience-interview/

\(^{12}\) https://voyant-tools.org/
3 Literature Review

In this chapter, a literature review is presented, addressing the main topics relevant to drone swarms, human-multi-drone interaction, and relevant SAR human factors, such as trust, cognitive workload and situational awareness. These areas are within the scope of this thesis work and their relation to each other are highlighted in this chapter. All of this is done in order to provide a comprehensive overview of the thesis background and to justify the decisions made for the implementation.

3.1 Search & Rescue Missions and the Role of Drones

Search and rescue (SAR) specializes in finding missing people. In many countries, the responsibility for this area primarily lies with the police force and fire departments, although some independent SAR teams may also operate, e.g. Swedish Sea Rescue Society \(^{13}\) and Missing People Sweden \(^{14}\) are two nonprofit organizations staffed by volunteers committed to assisting the Swedish police in SAR missions. Search and rescue missions cover diverse scenarios, typically categorized by terrain or specific circumstances guiding the search \(^{15}\). The different types of SAR operations can be divided as following:

- Air-sea rescue, also known as sea-air rescue, coordinates efforts to save individuals in maritime emergencies. Utilizing resources like helicopters, seaplanes, rescue boats, ships, and submarines, both military and civilian teams participate in these operations. Helicopter technology, enabling hovering, significantly transformed air-sea rescue methods.

- Ground SAR focuses on locating distressed or lost individuals on land or inland waters. It addresses diverse scenarios, including missing persons due to domestic issues, accidents, mental health challenges, or disorientation. Specialized units deal with environmental challenges like swift water, flood, thin ice, and over-snow rescues.

- Additional SAR operations encompass combat search and rescue in conflict zones, extracting individuals from challenging battlefield scenarios, and mountain rescue specialized in retrieving those stranded in dangerous mountainous terrain.

With an understanding of the various types of SAR operations, the following section will examine common challenges faced by SAR teams in their missions.

3.1.1 Challenges in Search & Rescue Operations

SAR teams are dedicated to rescuing those in need but face significant challenges. Key among these is the need for effective team communication for safety and success \(^{16}\). Communication issues can stem from tech issues or protocol breakdowns. Specialized communication software enhances intra team communication, improving accuracy and speed. It also aids swift information exchange between authorities and responders, simplifying emergency resource coordination.

\(^{13}\) https://www.sjoraddning.se/ [Accessed 2023-09-05]

\(^{14}\) https://www.missingpeople.se/sv/ [Accessed 2023-09-02]

\(^{15}\) https://flytbase.com/blog/drones-for-search-rescue [Accessed 2023-09-02]

The next challenge involves team member training. Proficiency in software tools and rescue techniques is crucial, along with a deep understanding of associated risks and mitigation strategies through education, practice, and equipment proficiency. Training covers various skills like confined space entry, cage rescue, helicopter long line operations, and high-angle rope access, developing rigging expertise for safety. This comprehensive training also gives familiarity with collaborative software and gear.

Lastly, time emerges as a critical factor, often combined with uncertainty regarding the exact location of individuals in distress [12]. SAR teams face the challenge of covering extensive areas within short timeframes. These demanding missions involve long hours, challenging terrain, and potential fatigue that can impact success. Operating in remote regions, these teams aim to aid the injured and locate missing individuals swiftly and safely, balancing speed with safety for optimal outcomes.

Despite facing challenges like unpredictable operations, limited timeframes, challenging terrains, training gaps, communication obstacles, time constraints, fatigue, and resource limitations, SAR teams persist in their dedication to saving lives. Drones offer potential solutions due to their flexible deployment capabilities. The next section will introduce the integration of drones into this context.

### 3.1.2 Drones in Search & Rescue Operations

An Unmanned Aerial Vehicle (UAV), commonly known as a drone, is an aircraft that operates without an onboard human pilot, controlled remotely or autonomously [17]. Despite being remotely operated, drones heavily rely on human control. Their components include the frame, motors, propellers, battery, flight controller, and various sensors. Operated via remote controls or smartphone/tablet applications, drones allow real-time control over movements, camera, and functions. Modern drones often feature obstacle avoidance and collision detection systems utilizing sensors and cameras to detect obstacles and adjust flight paths automatically, enhancing safety.

Unmanned Aircraft Systems (UAS) encompass the complete setup for UAV operations, including aircraft, ground control stations (GCS), communication links, software, and vital components [13]. UAS, comprising software and hardware, have diverse applications across government, military, civilian, commercial, and consumer sectors. Available in various sizes and capabilities, UAS perform multiple roles like data collection, logistics management, reconnaissance, weapon delivery, communication support, surveillance, research facilitation, and aerial photography [14]. The GCS, as a part of UAS, serves as the control station for managing UAV flight, enabling communication, control, and monitoring of the aircraft by pilots to perform tasks and gather data.

Drones revolutionize search and rescue by improving speed, accessibility, and data management [18]. They provide a swift, cost-effective method to collect aerial data, aiding efficient ground surveys and significantly improving the chances of promptly finding missing individuals. In unpredictable missions influenced by factors like time constraints and difficult terrains, drones play a crucial role. Here are the key benefits of utilizing drones in search and rescue:

- **Rapid Response**: Drones quickly navigate obstacles and reach remote areas faster than ground-based vehicles.

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17 [https://visionaerial.com/how-to-use-drones-for-search-and-rescue](https://visionaerial.com/how-to-use-drones-for-search-and-rescue), Accessed 2023-09-02
18 [https://www.flytbase.com/blog/drones-for-search-rescue](https://www.flytbase.com/blog/drones-for-search-rescue), Accessed 2023-09-04
• Situational Awareness: Providing quick access to aerial data, drones help map extensive search areas and identify potential locations of missing individuals.

• Detection and Recognition: With various sensors, including thermal cameras, drones effectively identify objects and individuals, especially in challenging environments.

• Communication: Equipped with loudspeakers, drones aid communication with missing individuals and ground teams, improving coordination.

• Lighting: Drones feature spotlights for improved visibility during nighttime operations.

Advancing UAV technology integrates automated flight, high-precision sensors, and machine learning algorithms, enabling these aircraft to rapidly gather extensive data, including images, videos, and sounds [13]. This data holds significant potential to aid search personnel in swiftly locating victims and assessing disaster situations in SAR missions. To utilize UAV data effectively, developing unsupervised data analysis techniques is crucial. Automation algorithms and machine learning can improve UAV autonomy, enabling autonomous target recognition, classification, tracking, and real-time decision-making. However, drones in SAR operations face limitations. Flight time is limited by battery capacity, and advanced payloads can decrease duration [15]. Bad weather conditions (strong winds, heavy rain, extreme temperatures) impact performance. Aviation regulations impose restrictions on altitude, airspace, and operations.

Effectiveness improvement depends on efficiently managing numerous UAVs, encouraging the adoption of multi-drone solutions.

### 3.1.3 Multi-Drone Operations: Swarm and Collaboration

In a drone swarm, multiple UAVs collaborate towards specific goals [16], where each drone can operate manually or autonomously via onboard processors. Assigned unique tasks for data collection and processing, each drone benefits from real-time computing. Centralized processing occurs on a server, base station, or cloud infrastructure. Utilizing multiple drones simultaneously through smart monitoring enhances coverage. Autonomous drone swarms, equipped with features like battery swapping, collision resilience, surveillance, and robust communication, aid search and rescue teams in swiftly identifying critical areas [17]. Transitioning from manual single-drone control to automated swarms requires technical advancements and professional engagement. While typically operated individually, ongoing research explores algorithms for autonomous drone swarms. Compared to a single drone, swarms cover larger search areas faster in rescue missions, increasing the chance of locating missing individuals.

Current research explores swarm control methods that don’t rely on low-level motor commands, drawing inspiration from natural models like bees, birds, and fish [16]. Investigating the concept of a leader among drones has also begun. A leader allows operators to focus on one drone, with others adjusting paths automatically. Drone control methods vary, from basic status monitoring to handling high-level mission priorities and search patterns. Managing multiple drones differs significantly from controlling a single one, necessitating unique interaction methods [18]. Despite the advantages, drawbacks hinder swarm implementation in SAR missions. Maintaining situational awareness (SA) is challenging, emphasizing the need for minimal user interface to aid error-free decision-making with drone swarms, as summarized in Figure 7. Interest grows in integrating UAV swarms into civilian airspace, driven by rising demand in military and civilian applications.
Resilient control and network adjustments for connectivity are essential in drone swarms, ensuring robustness even in potential losses [17]. Drones, equipped with diverse sensors, enhance real-time data collection for improved on-site response capabilities. Highly autonomous swarms streamline tasks, reducing execution time and improving fault tolerance. Challenges remain, particularly in establishing a reliable communication network, as structures vary based on tasks and drone autonomy, introducing implementation complexities.

Understanding how collaboration works in multi-drone operations prompts an investigation into the specific search patterns used within drone swarms.

3.2 Drone Swarm Search Patterns

The International Aeronautical and Maritime Search and Rescue (IAMSAR) comprises a set of guidelines and practices developed collaboratively by the International Maritime Organization [20] and the International Civil Aviation Organization [21]. These guidelines establish standardized procedures for conducting SAR operations in both maritime and aerospace domains. They offer essential guidance for operating drones, vessels, or other crafts involved in supporting SAR missions. IAMSAR includes commonly used search patterns like expanding square and parallel sweep track patterns, crucial in swarm-based advancements. These patterns, created through autonomous flight path planning and real-time adjustments, offer flexibility and utility for drone swarms. The choice of pattern depends on various factors such as search area size, available rescue units, time constraints, and environmental conditions.

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3.2.1 Expanding Square Search

One of the SAR convention’s specified methodologies is the expanding square search pattern, detailed within the IAMSAR guidelines, particularly for scenarios involving small craft or individuals who have fallen overboard [19]. Primarily intended for use by small SAR units, this pattern covers a large area, proving effective when the search object’s location is constrained within narrow parameters. It commences from a defined starting point and was designed for single-craft implementation, often suitable for vessels or small boats conducting searches in water for individuals or stationary objects. Its successful execution requires precise navigation skills. Typically, the initial leg of the search path aligns directly into the wind to minimize navigation errors, followed by course changes at 90-degree intervals. Figure 8a illustrates the coordinated movement of drones in a swarm following this pattern.

3.2.2 Parallel Sweep Search

The parallel sweep search pattern is used when the exact location of the target is uncertain, especially over vast water bodies or flat terrains. It divides large search areas into smaller sections, allowing multiple teams to operate simultaneously. This method is highly effective for ground SAR missions, starting from a specific midpoint within the search area’s corner. Search paths run parallel to each other and the longer sides, indicating drift direction for comprehensive coverage.

A team typically comprises a leader, two flankers (team members positioned on sides of the search area), positioned on the sides, and enough linemen to cover the required sweep width. Linemen line up along the initial edges, forming an effective search line. The leader oversees alignment and guides linemen with the help of flankers, one of whom acts as the pivot point to maintain the boundary.

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[19] Johanna Ahlskog

**Figure 8:** Two most common search patterns according to IAMSAR.
After completing the initial segment, the search line pivots around a flanker, returning in the opposite direction for a systematic and thorough search, maximizing the chances of finding the target object or individual. This is illustrated by Figure 8b.

Efficiently managing and designing user interfaces for human-multi-drone interaction is crucial due to the direct impact of drone swarm patterns on coordination, emphasizing the need for optimal performance.

### 3.3 Human-Multi-Drone Interaction

Understanding the dynamics and interactions between UAV pilots and multi-drones is critical for the success of effective SAR missions. Within the domain of human factors, cognitive workload and trust stand out as vital elements in the context of human-multi-drone interaction.

#### 3.3.1 Human-Multi-Drone Interaction in SAR Systems

Human-multi-drone interaction, a growing field in human-computer interaction, explores diverse applications like navigation, artistic expression, and multi-drone photography [21]. Efforts focus on developing interaction methods for future multi-drone piloting. Interviews with single-drone operators emphasize safety as their main concern in traditional drone piloting, prioritizing mission preparation and post-flight data management over flight duration itself [14].

In modern human-automation systems, monitoring plays a crucial role [22]. In today’s airplanes, autonomous systems handle many pilot duties, shifting their role to supervising automation. UAV pilots likely have more involved monitoring tasks integrated across operational levels. Unlike traditional aircraft cockpits, UAV ground control stations are expected to incorporate multiple dynamic displays [23]:

- Live onboard camera streams.
- Flight plan monitoring displays.
- Communication status indicators for Air Traffic Control, UAV operators, and UAVs.

Limited knowledge exists about integrating multi-drones into emergency response teams’ operations, including user interfaces, system message engagement, and airspace interaction [24]. Design considerations must prioritize information presentation and determine what’s essential, as extended monitoring stresses human capabilities, reducing problem detection over time.

Balancing these aspects optimizes human-multi-drone interactions and system usability. The growing demand for thorough monitoring in multi-drone systems increases mental workload, potentially overwhelming human operators with a constant overload of information. Addressing human factors, especially cognitive workload, is vital for safe UAV operations.
3.3.2 Cognitive Workload

Cognitive workload refers to the mental effort needed for task completion, involving processes like perception, decision-making, and problem-solving ([25]). As tasks grow complex, demand for attentional resources increases. Techniques to measure this workload aim to optimize human performance by efficiently managing cognitive resources. Managing stress and fatigue is crucial in demanding search and rescue missions ([24]). Strategies like proper rest, nutrition, and equipment training significantly impact effectiveness of the rescue team. Understanding cognitive workload guides the design of systems and user interfaces to align with human abilities, reducing mental workload and improving task performance.

Building trust is crucial in this scenario, as it not only assists in managing cognitive workload but also improving decision-making, thereby enhancing overall system performance and reliability.

3.3.3 Importance of Trust in Human-drone Interaction

Trust plays a pivotal role in human-multi-drone interaction, encouraging confidence and reliance between UAV pilots and drones ([25]). It’s vital for effective collaboration, decision-making, and ensuring faith in drone capabilities, seamless communication, and improved system performance. Trust significantly shapes users’ acceptance of advanced drone technology, optimizing interactions. Understanding the link between trust levels and reliance on the drone’s spatial context identification is crucial ([26]). Moreover, evaluating the establishment of trust involves assessing confidence in the drone’s responsiveness to termination actions.

3.4 Situational and Contextual Awareness in Search & Rescue Systems

Understanding situational and contextual awareness in SAR systems is foundational. Situational awareness encapsulates the real-time evaluation of conditions, while contextual awareness explores deeper, considering the broader implications and detailed factors influencing the situation ([27]). Together, they form a comprehensive understanding that aids responders in swiftly and effectively strategizing to address emergencies, optimizing outcomes in dynamic and challenging SAR scenarios.

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3.4.1 Importance of Situational Awareness

Situational Awareness (SA) is pivotal in understanding human-automation errors, often linked to phrases like ‘failure to maintain SA’ or ‘lack of SA’. In drone operations, pilots’ decisions heavily rely on their SA, crucial for effective decision-making. Endsley’s [28] definition from 1988 characterizes SA as “perceiving elements in the environment over time and space, comprehending their meaning, and foreseeing their future status.” This definition is structured around a three-level process.

- Level 1 - Perception of Elements in the Environment.
- Level 2 - Comprehension of the Current Situation.
- Level 3 - Projection of Future Status.

Figure 9 lays out the framework for exploring SA in decision-making, emphasizing the three SA levels. According to this model, an individual’s perception of environmental elements, sourced from system displays or sensory inputs, forms the core of SA, guiding subsequent action and performance [29]. SA development is influenced by factors like individual differences, experiences, and training. Personal beliefs also filter and interpret cues to construct SA. Additionally, the system’s information delivery capacity and task environment features, like workload and stress, significantly shape SA. Understanding these factors is crucial in comprehending SA dynamics in decision-making.

Figure 9: A conceptual diagram illustrating situation awareness and its three levels (based on [29]).
In Level 1, SA represents an individual’s environmental perception. Level two (comprehension) and level three (projection) hold particular significance in complex systems, influencing performance [28]. Temporal dynamics, such as time-related events, play an important role in these levels. While SA doesn’t inherently originate from systems, their design can enhance it by offering relevant information and user-friendly interfaces. Neglecting operators’ information needs during system design can significantly hinder achieving optimal situational awareness.

3.4.2 Contextual Awareness

The concept of SA aligns with the idea that individuals hold a mental model of their environment, while context awareness refers to an individual’s or system’s ability to understand and adapt to its surroundings by gathering and processing relevant information [27]. It encompasses an entity’s location, surroundings, and factors influencing its operations, often acquired through sensors or databases. Being context-aware means utilizing this information to adapt functionalities based on the current context [30]. Context-aware systems strive to offer personalized services by using information related to people, locations, timing, and events.

3.5 Lost Person Model in Search and Rescue

The Lost Person Model involves a conceptual framework aiding teams in understanding and predicting the behavior of missing individuals in outdoor settings [31]. This model, exemplified by probability maps, enhances SAR operational efficiency and effectiveness. With declining survival odds over time for a lost person, efficient search planning is vital. Typically, a spatial ‘ring model’ or Euclidean distance model is utilized, indicating potential distances based on past incidents [32]. This model uses quartile distance statistics, employing buffer rings around the Last Known Position (LKP) as probability circles. It integrates terrain and searcher capabilities [31], drawing rings around the Initial Planning Point (IPP) to optimize the search.

3.6 Data Visualization

Ben Shneiderman’s mantra in data visualization serves as a foundational principle for crafting advanced graphical user interfaces [33]. This mantra underscores the significance of providing users with a broad overview, empowering them to explore, concentrate on particular elements, and access deeper insights when necessary. It forms the basis for an engaging and interactive data visualization experience. This concept highlights three key aspects:

Overview First: Present a comprehensive visual representation of data to express its overall structure or patterns at first glance.

Zoom and Filter: Enable users to interactively focus on specific areas of interest or eliminate unnecessary information.

Details-on-Demand: Facilitate access to detailed information about specific data points upon user request.

[26] https://hampdatavisualization.wordpress.com/2016/02/26/schneidemans-mantra/
Accessed 2023-12-10
3.6.1 Heatmap in Search and Rescue

Heatmaps serve as powerful tools in data visualization, presenting complex information in an intuitive, colorful format [34]. These visualizations use variations in color intensity to represent data values, offering immediate insights into patterns, trends, and relationships within the dataset. Heatmap is a widely used in diverse fields statistical visualization method on matrix-like data.

Geoprocessing generates vital probability maps aiding decision-makers and SAR teams [35]. Overlaid on maps, heatmaps highlight zones, as described in section 3.5 into quartiles (25%, 50%, 75%, and 95%), as shown in Figure 10. They pinpoint search areas around the IPP for locating missing individuals.

Two maritime SAR cases illustrate two of the most common search patterns, as presented in section 3.2, displaying heatmaps with particle positions during the search [36]. Figure 11a displays search rectangles alongside their respective search patterns: expanding square search patterns in blue and purple rectangle and Figure 11b exhibits parallel line search patterns in similar colored rectangles.

Figure 10: Heat map visualizing lost person models (based on [35]).

Figure 11: Two most common search patterns together with heatmaps (based on [36]).

The next section presents to related work concerning state-of-the-art regarding multi-drone SAR systems. Firstly, it presents a comprehensive overview of real-world drone applications applications and existing research in this domain. Following that, a critical analysis is conducted to identify gaps and areas in need of further investigation.
3.7 Related work

In 2016, DJI \(^{27}\), a leading manufacturer in the drone industry, teamed up with DroneSAR \(^{28}\), an Irish tech startup, to launch a game-changing search and rescue application. This innovation merges a drone’s aerial view into management software, empowering rescue teams to utilize drones effectively in life-saving missions, as shown in Figure 12.

![Figure 12: A comparison of DroneSAR interface evolution between 2016 and 2022.](https://store.dji.com/se) Accessed 2023-11-27

DroneSAR’s application is a comprehensive tool facilitating real-time streaming of images and video captured by drones, whether equipped with regular or thermal imaging cameras. This feature allows seamless transmission of visuals to ground rescue teams. Crucially, the software possesses the capability to tag precise GPS coordinates of individuals in need, swiftly relaying this vital information via SMS or email. Such functionality empowers ground crews to respond rapidly, significantly reducing the time required to reach individuals in critical situations. Furthermore, the software logs completed search patterns, ensuring a comprehensive documentation that can be seamlessly pass crucial information to incoming rescue teams. Warnings messages and notifications are also present in the application.

The app’s notable strength lies in its adaptability across diverse terrains, enabling drones to navigate through mountains, trees, hills, or flat landscapes. This adaptability optimizes their flight paths for quicker and more efficient area surveys. Users have the flexibility to choose automatic aerial search patterns and tailor parameters such as field of view, altitude, battery life, and probability of detection.

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\(^{27}\) [https://store.dji.com/se](https://store.dji.com/se)

\(^{28}\) [https://dronesarpilot.com/](https://dronesarpilot.com/)

\(^{29}\) [https://dronesarpilot.com/](https://dronesarpilot.com/)
Through data collection, DroneSAR’s software facilitates systematic drone deployment as a fundamental component of rescue protocols. Remarkably, even today, this application continues to revolutionize its field.

There are currently few multi-drone systems in the industry. Red Cat Holdings recently introduced a pioneering four-drone integrated swarm system specifically designed for public safety, government, and defense markets. The primary interface of this system can be seen in Figure 13.

In collaboration with Teal Drones and Autonodyne, Red Cat introduces a pioneering system allowing one pilot to oversee up to four drones simultaneously. Notably, this marks the first US-produced drone system complying with strict Department of Defense guidelines. The system facilitates seamless control handoffs between pilots, ensuring uninterrupted 360-degree surveillance.

Red Cat promotes this innovation as a game-changer in drone operations, offering UAV pilots with real-time data from multiple drones while significantly reducing workforce expenses. Autonodyne’s CEO highlights the system’s fusion of human-machine interface and embedded autonomy, positioning it as an advanced solution for diverse intelligence and surveillance applications.

Current research, e.g. Williams et al., centers on investigating the involvement of drone swarms in search and rescue missions, particularly focusing on scenarios where UAVs collaborate closely. However, a noticeable research gap emerges concerning interfaces adjusted for UAVs operating independently in remote locations, requiring novel design approaches. This necessitates for new methods as existing proposals might not suffice. Managing varied map views and significant information during transitions between these UAVs poses considerable challenges in rapid comprehension and adaptation.
Agrawal et al. [38] explore the utilization of semi-autonomous UAVs in emergency operations such as search and rescue and fire surveillance. They underscore the complexity in designing effective solutions, aiming to strike a balance between human oversight, drone autonomy, safety protocols, mission efficacy, and the demands of stakeholders. The primary focus lies in increasing situational awareness through collaborative approaches, while acknowledging the gap between theoretical concepts and their practical implementation, particularly within interface design. Lochner et al.’s suggestions for automated or semi-automated systems play a pivotal role in automating tasks and furnishing information or recommendations for user guidance. They systems foster essential shared decision-making environments crucial for optimizing system efficiency. Therefore, their research highlights the significance of trust for users when navigating uncertainty in these contexts.

Itkin et al. [39] introduce a cloud-based web application designed for real-time monitoring and management of multiple UAVs within restricted airspace. This application provides comprehensive sensor data and a dynamic map overlay for easy monitoring while autonomously identifying and avoiding collisions. Hocraffer and Nam.’s review emphasizes the significance of customizing user interfaces for specific missions or swarm types, aiming to minimize cognitive workload. While promoting one-to-one interaction within swarms enhances efficiency, establishing universal guidelines applicable across diverse applications remains limited.

Källbäcker and Bjurling [41] underscores the need of comprehensive system design, strategies to reduce workload, and methods to foster trust, all aimed at enhancing collaborative efficiency within SAR teams. They highlight challenges like increased pilot workload and reduced situational awareness that can be mitigated through careful design considerations.

The study of multi-drone systems emphasizes the simultaneous evaluation of critical human factors such as situational awareness, cognitive workload, and trust. While exploring system design and multi-drone interfaces, gaps remain, especially in developing user interfaces for independent UAVs within drone swarms. Although situational awareness is crucial in emergencies, the translation of theoretical concepts into practical interface design presents challenges especially in how and which information is presented to the UAV pilot. Addressing these human factors simultaneously in user interface design will significantly improve the performance of multi-drone systems, particularly in demanding SAR scenarios and environments.

Further research in user interfaces for multi-drone systems is essential, building upon the existing studies outlined in this literature review.
4 Implementation and User Study Design

The aim of creating a proof-of-concept drone application is to evaluate the outcomes aligned with the research questions of this thesis, defined in section 1.3. The entire implementation process is carried out by the thesis author, with input provided by the author’s supervisors who have expertise in the field of drone swarm research. The prototypes developed for this thesis draw inspiration from the HERD prototype, as recognized in Chapter 2.1.

A system flowchart is shown below in Figure 14 to identify all the components and their interactions in the drone prototypes. The flowchart captures a set of typical interactions with the drone swarm, aiming to narrow down the thesis scope, and does not attempt to represent a complete model of swarm interactions. This is also done to identify how to integrate the design with the use case scenario. The following sections cover the individual components of the prototypes in more detail.

Figure 14: Flowchart of the drone prototypes
4.1 User Persona

As the initial part of the process for designing and implementing the drone prototypes, one user persona was developed using templates from FigJam\textsuperscript{35}, as detailed in Appendix A.1. This persona was created to explore the characteristics and requirements of potential end-users of the system, highlighting differences among users and their specific needs. The persona was based on distinct scenarios involving search and rescue missions, considering the demands and challenges of such operations as identified in the literature review. The main source for the user persona was interviews with real drone pilots found online.\textsuperscript{36}

The personality traits and needs of this persona was carefully crafted to reflect the realities of stressful SAR situations, adding a sense of authenticity and relevance to the profile. By using findings from the literature review, the persona was designed to evoke empathy and foster a deeper understanding of the issues faced by end-users. The ultimate goal was to gain valuable insights into how the multi-drone system can serve as a valuable tool for meeting the diverse needs of these individuals during their critical missions. Creating a user personal was useful before starting to develop the drone prototype.

4.2 Product Requirements of Drone Prototype

To guide and scope down the development process toward a solution representing important drone features and also suitable of addressing the research questions, a set of requirements was formulated and documented in Table 3. These requirements were conducted based on analysis of related work in Chapter 3.7, as well as insights gained from the collaborative research project presented in Chapter 2.1.

| Req. 1 | A map view displaying active drone swarms along with their intended flight path. |
| Req. 2 | A menu for displaying real-time drone information and status updates. |
| Req. 3 | Real-time telemetry data for all active drones. |
| Req. 4 | System messages providing UAV pilots system status information. |
| Req. 5 | Notifications to keep UAV pilots well-informed about critical events. |
| Req. 6 | Streaming real-time video data from drone cameras. |
| Req. 7 | Real-time obstacle detection in drone video feeds. |
| Req. 8 | Visualizing lost person model through a heatmap in the map view. |
| Req. 9 | Enabling one-on-one interaction with the drones in drone failure situations. |

This thesis specifically focuses on primarily mission monitoring components. The primary role of UAV pilots within this context is the continuous monitoring and potential intervene in the supervisory control tasks of multiple UAVs. The pilots are tasked with monitoring the UAVs for the majority of the mission duration and are prepared to assume control of a specific drone for landing in the emergency event. Each drone autonomously follows its designated predefined route, while a single UAV pilot oversees the collective behavior of the entire drone swarm. Table 4 illustrates the product requirements into the category mission monitoring, with proposed items or actions to be implemented in the drone prototype.

\textsuperscript{35}https://www.figma.com/templates/user-persona-template/ Accessed 2023-09-29

\textsuperscript{36}https://interviewprep.org/drone-pilot-interview-questions/ Accessed 2023-09-29
Table 4: Product requirements of the drone prototype divided into different mission monitoring components.

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C1</strong> Main map view:</td>
<td><em>(Req. 1, Req. 2, Req. 3, Req. 8 and Req. 9)</em> Convenient for both overseeing the collective behavior of drone swarms and individual interaction with each drone with also human consent.</td>
</tr>
<tr>
<td></td>
<td>• The flying area and limited area, as well as the actual search path and real-time location of the UAVs and drone map view.</td>
</tr>
<tr>
<td></td>
<td>• Telemetry data: Real-time data collected by UAV sensors.</td>
</tr>
<tr>
<td></td>
<td>• Human consent for starting/ending the mission, for object detection, and for UAV to land immediately.</td>
</tr>
<tr>
<td><strong>C2</strong> Notification icon:</td>
<td><em>(Req. 5)</em> Specific alerts with detailed instructions derived from the system status.</td>
</tr>
<tr>
<td></td>
<td>• Alerts.</td>
</tr>
<tr>
<td><strong>C3</strong> System messages:</td>
<td><em>(Req. 3 and Req. 4)</em> Information and warnings through text about external factors’ impacting the UAVs as well as the UAV’s status</td>
</tr>
<tr>
<td></td>
<td>• Current weather condition, GPS signal status, sensor status, battery level status, notifications of specific UAV.</td>
</tr>
<tr>
<td><strong>C4</strong> Drone status in drone side menu:</td>
<td><em>(Req. 2 and Req. 3.)</em> Real-time information of each UAV through a UI element which is not a system message.</td>
</tr>
<tr>
<td></td>
<td>• Amount of drones, GPS signal and battery level for each UAV.</td>
</tr>
<tr>
<td></td>
<td>• Telemetry data: Real-time data collected by UAV sensors.</td>
</tr>
<tr>
<td><strong>C5</strong> Video stream:</td>
<td><em>(Req. 6 and Req. 7)</em> Real-time video transmission with map view switching.</td>
</tr>
<tr>
<td></td>
<td>• Real-time video, object detection through the UAV’s sensors shown in the video stream.</td>
</tr>
<tr>
<td></td>
<td>• Telemetry data: Real-time data collected by UAV sensors.</td>
</tr>
<tr>
<td><strong>C6</strong> Heatmap:</td>
<td><em>(Req. 8)</em> Visualizing the lost person model through a heatmap on the map view.</td>
</tr>
<tr>
<td></td>
<td>• Visualization using a range of colors based on data intensity.</td>
</tr>
</tbody>
</table>
As part of this study’s objectives, the development involved creating two prototypes. The primary distinction between the two lies in the inclusion of an additional heatmap (C6), which will be described below along with the overall prototype components.

### 4.3 Drone Prototype 1

The project’s initial stage consisted of crafting a paper prototype, followed by the transformation of essential concepts into a software tool. Utilizing Figma\(^{37}\), the drone prototype together with its monitoring components were developed. Appendix A.2 displays several images presenting the finalized user interface views of the drone prototype.

Below, essential components of the drone prototype are outlined, giving a deeper understanding of its core elements.

#### 4.3.1 Drone Swarm Algorithm

As mentioned in section 3.2, parallel sweep search is one of the most common drone swarm search patterns for search and rescue. Parallel sweep search algorithms in search and rescue missions can vary in complexity depending on the specific scenario and the data structures used. The algorithm employed within the drone prototype operates as a basic parallel sweep search algorithm for drone swarms, navigating a grid-based environment from a home base, as described in section 3.2.2. This algorithm assumes that there are multiple drone swarms searching a grid for a target, as shown in Figure 15.

![Figure 15: Drone swarm flying the map view.](https://www.figma.com/) Accessed 2023-08-05

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\(^{37}\) https://www.figma.com/
4.3.2 User Interface Design Components

The components of the prototype have been assigned labels (C1, ..., C6), as previously detailed in Table 4. Table 5 presents the selected UI design components for the drone prototype. The color palette and typography were inspired by HERD’s prototype, as outlined in Chapter 2.1.

**C1 Main map view** contains
- Map view: Geographical map and search pattern.
- Icons: Drone icon, home base icon, symbolizing the drones and their starting point.
- Buttons: Emergency stop, video steam, land immediately, start/end mission, drone menu.
- Drone card: Contains telemetry data and drone status. This appears if a status alarm appears regarding a drone and when the system message turns either yellow or red.

**C2 Notification icon** is a component, which appears when the system is alarming an action, either to look at the video steam view, the drone map view or pressing the land emergency button. This appears if an alarm appears regarding a drone and when the system message turns red.

**C3 System messages** provide updates on drone status, events across application views, and drone surroundings, also issuing warnings when necessary. These messages categorize emergencies into three alert colors: Green, yellow, or red, based on the emergency level. For details on specific system messages utilized in the prototype, refer to Table 5.

**C4 Drone status in drone side menu** includes drone cards displaying drone numbers, signal status, battery status, and telemetry data like altitude, vertical speed, and flight time. The drone card changes color from green to yellow or red if any of the parameters fall below certain thresholds.

**C5 Video stream** includes four screens displaying live feeds from four drone cameras, accompanied by battery and signal status data, as well as orientation, latitude, and longitude information. An object detection box appears orange when no object has been identified. Once an object is detected by one of the drones, the object detection box turns red and triggers a notification together with a system message.

**C6 Heatmap on map view** is based on lost person model.

The drone application features four distinct views: the Main Map view, as shown Figure 15, Drone side map, as shown in Figure 16, Video stream view, shown in Figure 17, and the view for giving consent to end the mission. The inclusion of emergency and video stream buttons, along with the drone side menu, was inspiration from HERD’s drone prototype. However, specific drone components were developed and incorporated based on this thesis product requirements.
Table 5: Chosen UI components for the drone prototype.

<table>
<thead>
<tr>
<th>(C1) Main map view</th>
</tr>
</thead>
<tbody>
<tr>
<td>(C2) Notification icon</td>
</tr>
<tr>
<td>(C3) System messages</td>
</tr>
<tr>
<td>(C4) Drone status in drone map menu</td>
</tr>
<tr>
<td>(C5) Video stream view</td>
</tr>
<tr>
<td>(C6) Heatmap on map view</td>
</tr>
</tbody>
</table>

Table 6: System messages visible for the user, divided into the four different colors based on the level of emergency.

<table>
<thead>
<tr>
<th>Color</th>
<th>Messages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>New drone swarm take off</td>
</tr>
<tr>
<td></td>
<td>All drones have stable signal</td>
</tr>
<tr>
<td></td>
<td>Drone_X landed successfully</td>
</tr>
<tr>
<td></td>
<td>Always maintain visual contact with the drones</td>
</tr>
<tr>
<td></td>
<td>Person identified and rescue helicopter is approaching the area</td>
</tr>
<tr>
<td></td>
<td>All drones are recalled back to the starting point to clear the airspace</td>
</tr>
<tr>
<td>Orange</td>
<td>Weather Condition alert: Strong winds</td>
</tr>
<tr>
<td></td>
<td>Remember to watch the video stream</td>
</tr>
<tr>
<td></td>
<td>Drone_X has temporarily lost contact with the drones in the swarm</td>
</tr>
<tr>
<td></td>
<td>An issue with the camera on Drone_X has been detected</td>
</tr>
<tr>
<td></td>
<td>Low battery: Drone_X is soon below 20%</td>
</tr>
<tr>
<td></td>
<td>Low battery: Drone_X is below 20%</td>
</tr>
<tr>
<td>Red</td>
<td>Some object was detected</td>
</tr>
<tr>
<td></td>
<td>Almost lost contact with Drone_X</td>
</tr>
<tr>
<td></td>
<td>Battery level is too low for Drone_X to continue</td>
</tr>
<tr>
<td></td>
<td>Low battery: Drone_X is soon below 10%</td>
</tr>
<tr>
<td>No color</td>
<td>Is the detected object a human?</td>
</tr>
<tr>
<td></td>
<td>Do you really want to end the mission?</td>
</tr>
</tbody>
</table>
The mission initiates with one swarm take off, consisting of three drones, eventually leading after a while to the deployment of a total of 15 drones across five swarms. Events in the user interface occur every five seconds, intentionally increasing cognitive load and reducing situational awareness in the prototype. Users switch between the main map view, video stream and drone side menu, engaging with system messages until an object is detected by the drones. Upon detection, user consent is required to terminate the mission if the detected object really was a human, prompting all the drones to return home.

Events within the user interface include: object identifications via the video stream, notifications of low UAV battery levels, and other mission and battery-related events. In general, warning events prompt the display of system messages.

Figure 16: Drone side menu with each drone card, including the status of each UAV.

Figure 17: Video stream view with a detected object.
4.4 Drone Prototype 2

Prototype 2 is similar to prototype 1, sharing identical UI design components, drone swarm search pattern, the same number of active drones, similar types of events and system messages. However, prototype 2 introduces distinctive elements such as varied locations, changes in event sequencing, different camera footage, and most importantly, the addition of the heatmap component.

4.4.1 Heat Map based on Lost Person Model

Prototype 2 has been updated to facilitate mission control by incorporating a data visualization component of the lost-person behavioral model, detailed in Section 2.4, to aid the UAV pilot while monitoring the drone swarms. The lost-person behavioral model estimates the Probability of Area (POA) for each location within the search area over time. This drone prototype visualizes these POA values using a heatmap, pinpointing the location with the highest likelihood of finding the lost person. The heatmap is positioned within the middle of a parallel sweep pattern, similar as identified in the literature review, shown in Figure 11b.

As seen in Figure 18, the comprehensive heatmap is based on a Euclidean distance model. It marks the initial planning point based on the last known point (LKP) as a red triangle and outlines four symmetrical rings centered around the LKP. The outer rings are marked red, whereas the inner two rings are a part of the heatmap where darker colors to denote higher probability areas and lighter colors for decreasing probabilities. These rings indicate distances of 25%, 50%, 75%, and 95% for this subject category and terrain type, covering a 40×30 km region. The probability values are allocated accordingly, with the remaining 5% assigned to the area outside the 95% circle. These probabilities are further divided by the corresponding region’s area and allocated to individual pixels within the region. The map is limited to the 20×20 km evaluation region, displaying both the heatmap and the flight path during the mission execution.

Figure 18: The heatmap in the map view of prototype 2 based on lost person model.
4.5 User Study Design

With the prototypes implemented, the next phase is to apply the testing. As specified in Table 2 in Chapter 2.3, various research methods were utilized during the user study to address the research questions of the thesis. Each method plays an important role in assessing both qualitative and quantitative parameters, offering valuable insights into aspects such as trust, cognitive workload, situational awareness, and the usability of the implemented prototypes. These metrics collectively contribute to a comprehensive understanding of the prototypes’ performance and user experience.

4.5.1 Recruitment of Test Participants

The start of participants’ recruitment for the user study was done approximately one month before the conducting of the actual user study. This process started early in the thesis process, to make sure that test participants were found in time. The aim was to gather real-end users who could provide valuable feedback into the drone prototype’s performance and usability for mission-critical scenarios. The ideal target group for this study consisted of individuals who have experience in search and rescue missions, particularly those who use drones as part of their daily work, such as the Swedish police. In addition, the drone application’s user base extends to nonprofit organizations and individuals who engage in search and rescue operations.

The recruitment process involved reaching out to a wide range of Swedish institutions and SAR organizations through email. Efforts were made to contact with police departments and emergency services in various communities across Sweden. Additionally, bigger non-profit organizations focused on search and rescue operations were contacted to ensure representation from those engaged in volunteer-based efforts. This was done until a sufficient number of participants had been gathered for the user study.

4.5.2 Pilot Study and Improvements

The pilot study, conducted with a university student, was done to validate the methodology and technology for the user study. It highlighted several crucial issues for improvement. Adjustments were made to improve time management by sending the background questionnaire before user meetings, aiming to reduce overall duration, instead of letting the test participants answer it during the user study meeting. Potential technical issues during screen sharing in the study were also detected. Additionally, recognizing the lengthiness of the questionnaires, efforts were made to shorten it down. The training task prototype did also include unnecessary steps, which was then removed after running the pilot study. These changes made after the pilot study would make the main user study more efficient without losing any important information.

4.5.3 User Consent

In alignment with GDPR, all participants were requested to provide their consent before the user study, outlining the processing of their personal information and data. They were also told not to be given any rewards for their participation. This consent was essential, enabling video and camera recording during the user study. The consent form used was adapted from the Umeå University template.
4.5.4 User Study Overview

The user study was conducted online using either Zoom\textsuperscript{38} or Microsoft Teams\textsuperscript{39}. Camera and video recording were used within the software platforms to observe participants and their visual cues. The following is a summary of the user study procedure:

1. Before the user study meeting,
   (a) Provide sufficient information about the user study.
   (b) Ask for user consent.
   (c) Give the pre-questionnaire.
   (d) Book time for the user study meeting.
2. Start the user study meeting
   (a) Greeting and introduction to the participant.
   (b) Start video-recording.
   (c) Conduct a training session.
3. Present the user scenario.
4. Provide User task description for Prototype 1
   (a) Let the participant perform the user task in Prototype 1
   (b) Interrupt the participant three times to ask three SAGAT questions each time.
   (c) After it is done, give the post-questionnaire 1.
5. Introduce the modified user scenario.
6. Provide user task description for Prototype 2
   (a) Let them perform the User task 2
   (b) Interrupt the participant three times to ask three SAGAT questions each time.
   (c) After it is done, give the post-questionnaire 2.
7. Conduct a semi-structured interview and gather final thoughts on the prototypes.
8. End the user study meeting

4.5.5 User Training Session

The user training session is an important step before performing the tests. It aims to make sure attention and performance is measured fairly by promoting participant comprehension of the user interface. The intentionally simplified prototype utilized during training session focuses on showing key design elements and functionalities. During the training sessions, an initial overview of the drone prototype, followed by an opportunity for participants to freely explore the interface and ask for explanations. Finally, a short demonstration of drone swarm operations familiarizes participants with system monitoring. This approach ensures that during testing, the evaluation centers on participant engagement rather than only interface familiarity.

\textsuperscript{38}https://zoom.us/sv \textsuperscript{39}https://www.microsoft.com/sv-se/microsoft-teams/log-in

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4.5.6 User Scenario Descriptions

Before receiving the user task for Prototype 1, participants were presented with a user scenario described below. This introduction aimed to provide context on interacting with the prototype within a real-world search and rescue situation.

"You are working as a drone operator tasked with a search and rescue mission. Your role involves using drone swarms via an SAR application to monitor and control them during the mission. Upon receiving an emergency call, a flight path is generated within the SAR application, outlining the search area. Your responsibility is to oversee the drones’ status while the swarms autonomously navigate through the defined flight path.

Prepare for takeoff to execute the mission."

Similarly, before receiving the user task for Prototype 2, participants were presented with a modified user scenario:

"You are working as a drone operator in a search and rescue mission. In response to an emergency call, you now have access to a heat map displayed on the drone map view, created from the last known location of the missing person. As the drone swarms autonomously traverse the flight path, your careful attention is required, especially when flying over the heat map area.

Prepare for takeoff to execute the mission."

4.5.7 User Task Description

For both prototype 1 and prototype 2, participants were then instructed to perform the following task:

"Monitor the drone swarms until you find the missing person"

Participants were asked to think aloud, i.e. verbally express their thoughts and observations while interacting with the drone prototype. The participants perform the task, and finish when they think they have completed the task. Throughout the session, the test leader observed the participants’ behavior, noted their comments, and system interactions in a note-taking application. Additionally, the test leader reviewed camera and video recordings afterwards to capture any visual cues or details from the participants.
4.5.8 Situation Awareness Global Assessment Technique Questions

While performing the user task in the prototypes, SAGAT questions were asked in sets of three, with each set containing one question related to each of the three levels of SA. This questioning procedure was done when the prototype was paused unexpectedly at certain points in the prototype flow, using the so called the freeze technique. Moreover, the SAGAT questions of the three levels of SA would incorporate the pilot’s present understanding of the various design components within the interface. Table 7 presents SAGAT questions used in the user study categorized according to various design components $C1 - C6$ and the three levels of SA. The scores of SA are determined based on the correctness of responses to SAGAT questions.

Table 7: SAGAT questions in the user study, covering various UI components and the three levels of situation awareness.

<table>
<thead>
<tr>
<th>#</th>
<th>Component</th>
<th>Question for SA Level 1 (Perception)</th>
<th>Question for SA Level 2 (Comprehension)</th>
<th>Question for SA Level 3 (Projection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Main map view</td>
<td>Which drone caused the object alert?</td>
<td>What is the current battery level of the drone, shown as a drone card?</td>
<td>How many active drones are currently flying after you have clicked the button?</td>
</tr>
<tr>
<td>C2</td>
<td>Notification icon</td>
<td>Which drone caused the object alert?</td>
<td>What is the current battery level of the drone, caused the object alert?</td>
<td>What will happen next in the application?</td>
</tr>
<tr>
<td>C3</td>
<td>System messages</td>
<td>Which color was the latest system message?</td>
<td>What was the latest message?</td>
<td>How many drones will you see in the next view of the application?</td>
</tr>
<tr>
<td>C4</td>
<td>Drone status in drone side menu</td>
<td>Which drone caused the object alert?</td>
<td>What was the last system message to alert on the drone menu?</td>
<td>What will happen next in the application?</td>
</tr>
<tr>
<td>C5</td>
<td>Video Stream</td>
<td>Which drone did show a human in the camera feed?</td>
<td>What was the last system message in the video stream view?</td>
<td>What will happen next in the application?</td>
</tr>
<tr>
<td>C6</td>
<td>Heatmap</td>
<td>Which drone caused the object alert?</td>
<td>How many active drones are currently flying over the heat map in the map view?</td>
<td>What will happen next in the application?</td>
</tr>
</tbody>
</table>

4.5.9 User Study Questionnaire Details

This section outlines the breakdown of the user study questionnaires utilized:

1. Pre-questionnaire was completed by participants before the user study. It included:

   1. Demographics: Gender, age.
   2. Main occupation: Institution/Organization, role, position, and department.
   3. Previous experience: Years of experience in drones and/or search and rescue missions and major context of drone application.
   4. VAS-scale: Current stress level.
   5. Emocards: Current emotional state.
2. Post-questionnaire for Prototype 1 consisted of:

1. Nasa-TXL: Cognitive workload
2. Emocards: Current emotional state.
3. SEQ: Task difficulty.
4. Human-computer trust scale: Statements on ability, integrity, benevolence (rated on a 1-7 Likert scale).

3. Post-questionnaire for Prototype 2 included:

1. Nasa-TXL: Cognitive workload
2. Emocards: Current emotional state.
3. SEQ: Task difficulty.
4. Human-computer trust scale: Statements on ability, integrity, benevolence (rated on a 1-7 Likert scale).
5. Human-computer trust scale: Statements specifically for the heat map component (rated on a 1-7 Likert scale).
5 Results

This thesis primarily focuses on investigating various human factors affecting UAV pilots during their interactions with a multi-drone system, as detailed in Chapter 1. Throughout the study, participants were asked to engage in user task scenarios while using two drone prototypes, as described in Chapter 4.5. They were instructed to execute the tasks to the best of their ability, and afterwards give their feedback on the prototypes. The key findings are summarized into the following main quantitative and qualitative outcomes:

1. There was a significant cognitive workload, where SA varied slightly based on the component and SA level.
2. System messages were visible, but with low comprehension.
3. The heatmap did contribute to increasing some aspects of trust.
4. Positive feedback has been received regarding flying drone swarms, but UI iterations are necessary before replacing real-life single-drone systems.
5. The most requested features involve thermal cameras and incorporate a specific level of manual control of each drone during emergency situations.

The user study took place over a two-week period in mid-November 2023. Conducted in Swedish, all user study materials, including questionnaires, were in Swedish, while the prototypes were in English. The testing phase went smoothly for all participants, and remarkably, everyone completed the user study successfully within 60 minutes.

5.1 Participant Demographics

All participants in the prototype’s user study (N = 10) had previous experience in working with single-drones and SAR operations across various institutions and SAR organizations in Sweden, as detailed in Table 8. They were selected based on their expertise in this domain. Among these participants, there was 1 female participant and 9 male participants. The participants’ ages ranged from 25 to 65 years, with a mean age of 44 years (SD = 12.07). These participants work in different parts of Sweden, as illustrated in Figure 19. Their experience in SAR varied from 2 to 22 years, with a mean experience of 10.60 years (SD = 7.49).

Table 8: Background of participants (N = 10)

<table>
<thead>
<tr>
<th>Institution/SAR organization</th>
<th>Participants</th>
<th>Educated UAV pilot</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Swedish Police</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>Swedish Sea Rescue Society</td>
<td>3</td>
<td>Yes (2), No (1)</td>
</tr>
<tr>
<td>The Swedish Maritime Administration</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Missing People Sweden</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Emergency service</td>
<td>1</td>
<td>Yes</td>
</tr>
</tbody>
</table>

According to Table 8, a significant majority (90%) of the participants are educated UAV pilots. Their experience with drones varied from 1 to 10 years, with a mean experience of 4.10 years (SD = 3.10). Except for UAV piloting, participants mentioned diverse roles such as police officers, police assistants, leaders/managers in SAR operations, maritime crew members, and individuals involved in SAR research and development.

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5 RESULTS

![Image of a map showing the geographical distribution of participants across Swedish counties.](image)

(a) Number of participants per county in Sweden.

(b) Geographical distribution.

<table>
<thead>
<tr>
<th>County of work</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire Sweden</td>
<td>2</td>
</tr>
<tr>
<td>Norrbottens county</td>
<td>2</td>
</tr>
<tr>
<td>Jämtlands county</td>
<td>1</td>
</tr>
<tr>
<td>Jönköpings county</td>
<td>1</td>
</tr>
<tr>
<td>Västerbottens county</td>
<td>1</td>
</tr>
<tr>
<td>Västernorrlands county</td>
<td>1</td>
</tr>
<tr>
<td>Västra Götalands county</td>
<td>1</td>
</tr>
<tr>
<td>Östergötlands county</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 19: Distribution of participants across Swedish counties (N = 10)

The major application context and experiences of drones mentioned among these participants involved traffic and public gathering monitoring, surveying, filming, crime prevention, crime scene investigations, missing person searches as well as using drones for maritime rescue and firefighting purposes. All participants expressed the importance of drone technology within their organizations, and they were curious about the latest research solutions.

5.2 Visual Analogue Scale (RM1)

VAS was utilized before the user study with the primary goal of measuring participants’ stress levels. The scale spanned from 1 to 10, representing a range from relaxation (1) to extreme stress (10). This measurement aimed to evaluate the current stress levels of participants and investigate any potential connections with their cognitive workload and situational awareness during the study. The participants’ stress level ranged from 1 to 4, with a mean value of 2.3 (SD = 1.14), as presented in Figure 20. After analyzing the data, it became apparent that all participants reported stress levels indicating a state of relaxation rather than stress. Therefore, their low stress levels could not influence their results of cognitive workload and situational awareness of the study.

![Box plot illustrating participants’ stress levels measured using the VAS.](image)

Figure 20: Box plot illustrating participants’ stress levels measured using the VAS before the user study, on a 10-point Likert scale from “Relaxed” to “Extremely stressed”.

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5.3 Situation Awareness Global Assessment Technique (RM2)

The quantitative SA scores were calculated from participants’ accuracy in responding to SAGAT questions for each component and SA level, which each SAGAT question was described earlier in Table 7. Unexpectedly interrupted during prototype use, each participant encountered three sets of SAGAT questions per prototype. Each set contained three individual questions corresponding to SA levels 1 through 3, each linked to a specific UI component.

The main results are presented in Table 9 and it reveals that the UI overall, resulted a moderate level SA, achieving an accuracy of 54.44% across all 18 SAGAT questions. Notably, SA varied based on different levels: SA level 3 (projection) achieved the highest accuracy of 63.33%, followed by SA level 1 (perception) at 53.33%, while SA level 2 (comprehension) achieved a relatively lower accuracy of 46.66%.

Table 9: Summary of responses from participants (N = 10) for SAGAT questions covering various design components and levels of SA. The summary shows correctness of participant responses (in percentages)

<table>
<thead>
<tr>
<th>#</th>
<th>Component</th>
<th>Accuracy on SA Level 1 (Perception)</th>
<th>Accuracy on SA Level 2 (Comprehension)</th>
<th>Accuracy on SA Level 3 (Projection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Main map view</td>
<td>70% Correct</td>
<td>60% Correct</td>
<td>60% Correct</td>
</tr>
<tr>
<td>C2</td>
<td>Notification icon</td>
<td>20% Correct</td>
<td>60% Correct</td>
<td>40% Correct</td>
</tr>
<tr>
<td>C3</td>
<td>System messages</td>
<td>60% Correct</td>
<td>20% Correct</td>
<td>70% Correct</td>
</tr>
<tr>
<td>C4</td>
<td>Drone status in drone side menu</td>
<td>50% Correct</td>
<td>90% Correct</td>
<td>50% Correct</td>
</tr>
<tr>
<td>C5</td>
<td>Video stream</td>
<td>70% Correct</td>
<td>30% Correct</td>
<td>80% Correct</td>
</tr>
<tr>
<td>C6</td>
<td>Heatmap</td>
<td>50% Correct</td>
<td>20% Correct</td>
<td>80% Correct</td>
</tr>
</tbody>
</table>

Table 10 illustrates the evaluation performed to identify the component that provided the highest and lowest SA on the user interface. SA scores for various UI components labeled as C1, ... , C6 were calculated. The findings indicate that C5 (Video Stream) demonstrated the highest SA accuracy, reaching 60%, while C2 (System messages) exhibited the lowest SA accuracy, standing at 36.66%. The SA scores for the remaining components were closely grouped, ranging between 50% and 60%.

Table 10: Correctness of each component based on SAGAT questions (in percentages).

<table>
<thead>
<tr>
<th>Component</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>63.33 %</td>
<td>36.66 %</td>
<td>50.00 %</td>
<td>50.00 %</td>
<td>60.00 %</td>
<td>50.00 %</td>
</tr>
</tbody>
</table>

5.4 NASA Task Load Index (RM3)

After completing both task 1 and task 2 after each prototype, participants evaluated their mental workload using NASA TLX. Utilizing a 10-point scale from low to high, i.e. raw ratings, each participant assessed the six NASA TLX subscales. The figures in 21a and 21b display the raw ratings, mean, and median values for each participant and subscale, while Figure 21c illustrates a comparison between these two tasks.
RESULTS

(a) Results of raw rating from task 1

(b) Results of raw rating from task 2

(c) Comparison between task 1 and task 2 regarding mean and median values

Figure 21: Results from task 1 and task 2, related to NASA-TLX

The comprehensive weight for each participant, for each task, is determined by the multiplication of the raw rating and the weight rating. In Figure 22 there is a representation of the standardized overall workload for each participant, considering their individual weight ratings. On average, the total workload amounted to 51.88, reaching a maximum of 80.83 and a minimum of 40 for task 1, and a maximum of 62.5 and a minimum of 38.33 for task 2.

Figure 22: Graph illustrating the comprehensive weight outcomes

The comparison between task 1 and task 2, illustrated in Figure 21, revealed some interesting differences. Overall, participants found task 2 to be slightly more mentally demanding than task 1. However, task 2 was less frustrating, creating a more comfortable experience than task 1.
In task 1, participants rated the mental challenge differently, experiencing varying levels of frustration, impacting their perceived effort and performance. Task 2, however, was perceived as slightly less mentally taxing and less frustrating, with similar performance and perceived effort compared to task 1.

In summary, both prototypes required a significant cognitive workload. Notably, task 2 exhibited a slightly lower cognitive workload compared to task 1.

5.5 Emocards (RM4)

Through the use of emocards, participants were asked to express their current emotions before the user study, after using prototype 1, and after using prototype 2. This allowed for expressing of their emotional states at different stages during the testing phase. The results from the emocards in Figure 23 align with the picture representations, shown in Figure 6.

![Emocards](image)

Figure 23: Emocards results were gathered for each participant at various testing stages.

As seen Figure 23, most participants indicated experiencing emotions ranked as average pleasant (3) and calm pleasant (4) after using both prototypes. These emotions tended to slightly shift by one step up or down in number during the testing stages. A few participants consistently selected the same emotional card across all three test phases. For example, participant 9 regularly identified the emotion as excited pleasant. However, there were two exceptions. One participant initially felt calm pleasant (4) before the study, shifting towards a neutral excitement (1) after using both prototypes.
On the other hand, another participant moved towards feeling *calm unpleasant* (6) by the end of the testing. As seen in Figure 23 before the user study, the average emocard value was 3.5, with a standard deviation of 0.707. After using prototype 1, the mean emocard value decreased to 2.90 (SD = 0.871). However, following prototype 2, the mean emocard value slightly increased to 3.00, accompanied by a higher standard deviation of 1.069.

The majority reported *average pleasant* (3) emotions, followed by *calm pleasant* (4), indicating a potential transition from excitement to calmness. Although there was a slight convergence in participant responses whether to start with *average pleasant* (3) or *calm pleasant* (4) during the user study. However, this consistency might still suggest positive user experiences with the prototypes.

### 5.6 Single Ease Question (RM5)

The majority of participants successfully completed the tasks in both prototypes. In prototype 1, 80% of the participants accomplished the task, while all participants (100%) in prototype 2 succeeded. Notably, one participant who did not complete the task in prototype 1 pressed the emergency stop in prototype 2 due to low battery but reconsidered, intending to resume the mission.

To evaluate how user-friendly the prototype is, the difficulty of two user tasks were measured: Task 1 in prototype 1, which focused on monitoring drone swarms until a person was found, and task 2 in prototype 2, an extension of the previous task that incorporated an additional focus on the heatmap component. Participants were asked to rate the ease of these tasks on a scale of 1 to 7, from "Very easy" to "Very difficult." The normalized results are represented in Figure 24.

![Figure 24: Box plot comparing SEQ scores between Task 1 and Task 2](image)

By conducting a paired t-test, the ease of performing task 1 compared to task 2. The outcomes, presented in Table 11 revealed no significant difference between the task in prototype 1 (M = 4.60, SD = 0.866) and the task in prototype 2 (M = 3.80, SD = 0.781). Both tasks showed no significant difference. However, task 2 seemed slightly easier than task 1, although both remained challenging.

<table>
<thead>
<tr>
<th>Task</th>
<th>Mean</th>
<th>SD</th>
<th>95% CI for MD</th>
<th>df</th>
<th>Cohen’s d</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1/Task 2</td>
<td>4.60/3.80</td>
<td>0.866/0.781</td>
<td>[0.017, 1.583]</td>
<td>9</td>
<td>0.731</td>
<td>2.312</td>
</tr>
</tbody>
</table>
5.7 Human-Computer Trust Scales (RM6)

The trust aspects tested using Likert scales within the questionnaires, as specified in B.1 are ability, integrity, and benevolence. The quantitative analysis involved a paired t-test to measure whether participants’ trust in the system differed between prototype 1 and prototype 2, the later incorporating the heatmap. The analysis was structured around the following hypotheses, aligning with RQ2.

\[ H_0: \text{There is no significant increase in trust when using the heatmap based on the lost person model in the search and rescue system.} \]

\[ H_A: \text{There is a significant increase in trust when using the heatmap based on the lost person model in the search and rescue system.} \]

The analyses were conducted on a question-by-question basis. The results of comparing prototype 1 and prototype 2, based on the provided t-statistics and p-values, are presented in Table 12. For ability, the t-statistics are mostly close to zero, suggesting no significant difference between most metrics of ability in prototype 1 and prototype 2. All p-values are high (close to 1), indicating insufficient evidence to reject the null hypothesis, meaning there’s no significant difference in ability metrics between prototype 1 and prototype 2.

For integrity, some metrics in the t-statistics show positive and relatively larger t-statistic values in prototype 2, implying potentially higher integrity-related metrics in prototype 2 for those specific parameters. The p-values, although lower than ability, are not extremely low. They suggest that while there might be differences in certain integrity-related metrics, they might not be extremely significant.

For benevolence, prototype 2 shows larger t-statistic values, indicating potentially higher benevolence-related metrics in prototype 2 for those specific parameters. The p-values are notably low (as lowest 0.015), suggesting strong evidence against the null hypothesis and indicating a significant difference in some benevolence-related metrics, favoring prototype 2. These mean differences between the prototypes can also be viewed in Figure 25.

Table 12: Paired t-test raw data for comparing prototype 1 and prototype 2, related to the human-computer trust scale.

<table>
<thead>
<tr>
<th>Trust Aspects</th>
<th>Statistical test results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T-statistic</td>
</tr>
<tr>
<td>Ability</td>
<td>[0, −0.318, 0.318, 0.152]</td>
</tr>
<tr>
<td>Integrity</td>
<td>[1.627, 1.246, −0.802, 1]</td>
</tr>
<tr>
<td>Benevolence</td>
<td>[−1.464, 1.309, 1.711, 3]</td>
</tr>
</tbody>
</table>

Table 13 displays the results from specific heatmap-related Likert scale questions associated with prototype 2, these 4 questions can be found in Appendix B.1. These results reflect opinions on the heatmap. In general, there was a more positive than negative attitude toward the heatmap, as evidenced by the mean score of all questions at 4.08 (SD = 0.89) on a 7-point Likert scale.
As summary, the comparison between prototype 1 and prototype 2 reveals no significant differences in ability, a little bit higher integrity-related metrics in prototype 2. However, there’s a notable increase in benevolence when using prototype 2 compared to prototype 1. These findings support the null hypothesis for ability and integrity while affirming the alternative hypothesis for a significant increase in benevolence with prototype 2. Opinions of the heatmap were also more towards positive than negative.

In summary, the comparison between prototype 1 and prototype 2 reveals no significant differences in ability, a slightly higher integrity-related metric in prototype 2, and notably increased benevolence in prototype 2 compared to prototype 1. These findings support the null hypothesis for ability and integrity while affirming the alternative hypothesis for a significant increase in benevolence with prototype 2. Opinions about the heatmap were generally more positive than negative.

Table 13: The findings gathered from the 4 human-computer trust scale statements, rated on a 7-point Likert scale, specifically about the heatmap.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Mean</th>
<th>Median</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.5</td>
<td>4.5</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>4.3</td>
<td>4.5</td>
<td>0.9</td>
</tr>
<tr>
<td>3</td>
<td>4.2</td>
<td>4.0</td>
<td>0.87</td>
</tr>
<tr>
<td>4</td>
<td>3.3</td>
<td>3.5</td>
<td>1.27</td>
</tr>
</tbody>
</table>
5.8 Semi-structured Interviews (RM7)

At the end of the user study, a semi-structured interview was conducted to collect participants’ feedback. Five main questions were asked, focusing on the participants’ opinions regarding the prototypes. Figure 26 shows a word cloud generated from the post-experiment interviews, where the words "drone(s)" , "swarm(s)" , "contact" , "information" and "programmed" are the most frequently used. Further insights into the participants’ quotes from the interviews, is available in Appendix B.2. Additionally, this section includes observations made by the facilitator and participants’ own comments while using the prototypes.

![Word Cloud Image]

Figure 26: A word cloud visually representing the 25 most frequently spoken Swedish words during post-experiment interviews by participants, with word size indicating word frequency.

5.8.1 General Feedback of the Prototypes

The overall impression of the prototype resulted in a mix of positive and negative feedback, with comments from describing it as a ‘useful tool’ and ‘interesting’ to also finding it ‘stressful’ and ‘demanding’. As it was the participants’ first time experience flying drone swarms, they expressed a sense of newness and unfamiliarity. However, they noted that with more practice, they would learn the best ways to use the system.

Participants highlighted a significant advantage of the prototype: the ability of drone swarms to improve search and rescue missions by enabling more efficient searches, acknowledging the critical importance of time in these scenarios. The majority of participants expressed same type of comment:

"I could absolutely consider using drone swarms like this in reality. However, it needs to be reviewed how to represent important information."
Negative feedback of the prototype primarily centered around the stress caused by managing multiple drones and handling numerous warnings arising from drone failures. Frustration was expressed regarding the limitations perceived in dealing with autonomous drone swarms, specifically the lack of choices other than emergency landing or aborting the mission. According to most participants, the UAV pilot should maintain the authority to decide whether a drone continues or stops, rather than solely relying on the autonomous drone swarms:

"I didn’t feel like I had sufficient control of the drone when warnings appeared – For example with low battery level, it would have been good to be able to choose to send a drone home or choose to land immediately. This is needed to be able to fly in a real-life environment."

5.8.2 Drone Swarm Monitoring Attention

All participants expressed that keeping track of all drones became difficult, despite the assistance provided by the prototype through system messages and notifications. Some participants were unable to say how they managed their attention among drone swarms. However, many participants highlighted that they relied on system messages to focus their attention on the events displayed on the map view, even when numerous drones were active. One participant suggested a realistic size for a manageable drone swarm:

"Fewer drones to keep track of. Monitoring four to five drones simultaneously would be manageable."

5.8.3 Evaluation of System Messages

During the interview session, various opinions were shared regarding the system messages. While the system messages served the function of aiding UAV pilots in maintaining focus, participants highlighted the overwhelming frequency of these messages. At one point, a UAV pilot nearly missed locating a person due to the overwhelming of messages, an event crucial to the mission’s success. A suggestion from one participant summarized the need for reduced information:

"Filter out what information is crucial and what is unnecessary, when there are many drones to monitor."

Participants also expressed a desire for message to be saved; currently, messages disappear once shown for a while. Suggestions were made for warnings to persist until manually removed, utilizing for example a scrolling log list for reviewing notifications missed in real-time. Another suggestion from participants involved centralizing notifications related to system messages.

A participant proposed relocating the system message bar to the upper row, aligned with the emergency stop, video stream and drone map buttons. This adjustment aims to minimize screen distraction, allowing focus solely on the drone swarms within the map view:

"To have the warnings more centralized and not spread out, so that I don’t need to look around constantly."
5.8.4 Heat Map Analysis

Participants generally held a positive attitude towards the heatmap. However, in this particular mission scenario where multiple drone failures occurred, some UAV pilots found it challenging to focus on the heatmap when monitoring the drones’ movements on the map view. There were discussions regarding a potential correlation between the search pattern and the heatmap on the map view:

"I like it, it could have been better if there was an option to begin the search from that specific point in the heatmap and then create the flight route from there. Personally, I would prefer to investigate that area first."

One participant emphasized the significance of the LKP in their institution, often serving as the initial starting point for defining the search area. However, another participant pointed out that while the LKP and the heatmap are relevant, the presence of a heatmap doesn’t guarantee the person’s location within that specific area with different drone swarms.

5.8.5 Desired Features Feedback

When asked about missing key features, UAV pilots gave many suggestions. Some proposed improvements to the user interface, such as adding sound to accompany systems messages if a warning occurred and incorporating zoom functionality for cameras in the video stream view. Others suggested additional features, including night vision capability and the ability to create different search patterns, e.g., starting from the LKP or conducting searches in various sub-areas.

The absence of thermal cameras, essential tools for most UAV pilots, was a notable missing in this prototype, making it a crucial feature. As one participant expressed:

"Combining thermal and regular cameras would make it much easier to detect people in this prototype."

5.8.6 Participant Observation and Visual Cues (RM8)

The main issue identified by UAV pilots with the prototype was the inability to manually stop a drone when they detected something of interest. UAV pilots expressed a keen interest in getting a closer look at detected objects, indicating a desire to further investigate rather than simply passing through with the autonomous drone swarms, considering the possibility that it might be the missing person:

"It would have been interesting to investigate this further, if I only could manually control a drone to stop at the possible object."

One participant talked for themselves and asked in the event of losing contact with a drone within a swarm, how is the situation managed by the remaining drones in the swarm during the period of lost communication. Another participant commented if it was possible to view all drones within the video stream apart from these four available.
During the first task in prototype 1, surprisingly almost all participants commented the following when they saw it for the first time: the system message warned about low battery status of a drone:

"This drone has low battery it will most probably return home immediately."
6 Discussion

This chapter presents a comprehensive analysis of the collected results from the user study and it discusses the interpretation of findings from a research question point of view. Additionally, this chapter explores limitations encountered during the study and discusses the potential design implications arising from the findings.

6.1 Interpretation of Results

The study’s outcomes can be summarized into several significant quantitative results. Firstly, participants indicated low levels of stress prior to engaging in the user study (RM1). Secondly, the scores for SA varied across different components and SA levels (RM2). While using the prototypes, participants experienced a notable cognitive workload, although this workload slightly decreased during the use of prototype 2 (RM3). Additionally, most participants described their experience with the prototype as average or pleasantly calm (RM4). Task 2 was perceived as slightly less demanding than task 1, yet it remained challenging (RM5). Moreover, prototype 2 demonstrated a significant increase in the trust aspect benevolence compared to prototype 1, despite no notable differences in the trust aspect ability and the trust aspect integrity (RM6).

However, because of the limited number of participants, direct conclusions from these quantitative results cannot be made. Instead, the most significant findings are emphasized from the qualitative data, which includes important expert feedback. Participants expressed a strong desire for features such as monitoring fewer drones, combining sound with warnings, and having control over landing and the return-to-home function for each UA V. While the heatmap was appreciated by the participants, there was also a need for a review of system messages (RM7). Despite this factor, positive feedback was received regarding the concept of flying drone swarms. However, it was noted that UI improvements are necessary before it can effectively replace real-life single-drone systems as stated by Källbacker and Bjurling [41].

The study’s comprehensive findings highlight the potential of the multi-drone prototype. Yet, a unanswered question remains regarding the optimal presentation of crucial information to drone pilots. Expanding on Lochner et al.’s work [42], this underscores the importance of providing users with informative or actionable recommendations. Their claim about the impact of automatic or semi-automatic systems in fostering collaborative decision-making environments for optimal system utilization resonates with this extended research. Nevertheless, these results underscore the UAV pilots’ preference for complete manual control during critical drone actions.

Further insights from the user study examine how the limited number of participants, who initially underwent a brief training session and then utilized prototype 1, might have impacted the improvements observed in the results of prototype 2. This could significantly affect the outcomes. It would be interesting to investigate the extent to which this influenced the differences observed in the effectiveness of the prototypes.

This is further discussed in from a research question point below. Through the gathered results it is possible to oversee the hypotheses, defined in section 1.3.
6.1.1 RQ1: Visibility of System Messages

The SAGAT questionnaire results revealed significant variability in SA among participants. While 60% of them mastered system messages perfectly, comprehension notably dropped to 20% when only text with different emergency colors was visible. On the other hand, UI components illustrating drone status or notification icons received much higher comprehension SA scores during the test.

Post-experiment interviews provided valuable insights into the current implementation’s pros and cons. Particularly noteworthy was the dissatisfaction expressed by UAV pilots regarding the amount of system messages and other warnings in the prototype. However, they recognized the importance of the warnings and made every effort to follow them as much as possible. H1 was defined in section 1.3:

\[ H1 \text{ Visible system messages enhance situational awareness in search and rescue multi-drone system.} \]

As such, H1, related to enhancing situational awareness through visible system messages, was potentially validated.

6.1.2 RQ2: Trust with Heatmap

The results from the human-computer trust scale offer valuable insights for future research and comparative studies. These findings can also guide further development of the heatmaps. Notably, the trust aspect that showed an increase was benevolence, as illustrated in Figure 25. This outcome aligns with the task design, offering useful insights for future improvements.

Additionally, responses from the 7-point Likert scale regarding the heatmaps displayed a positive attitude toward this component, with a mean score of 4.08. However, making these heatmaps effective relies on careful design choices for colors, normalization, and context of use. Although they improve understanding, challenges persist in ensuring the accurate use.

Regarding cognitive workload during prototype usage, as shown in Figure 22, the average overall workload among participants was 51.88, with variations across individuals. Participants expressed in post-experiment interviews that the tasks were demanding and stressful, as supported by the SEQ results in Figure 24. This suggests significant cognitive demands within the user scenario, providing insights for future tests of similar kind. The second hypothesis was defined in section 1.3:

\[ H2 \text{ A heatmap using the lost person model increases trust in multi-drone pilots during high-cognitive-workload monitoring in a search and rescue system.} \]

Moreover, these results support H2, indicating that heatmaps increase trust during high-cognitive-workload monitoring of drone swarms.
6.2 Limitations

Due to time constraints, the drone prototypes were developed in single iteration of the double diamond model. As a result, these prototypes were exclusively created using Figma. With better time management, these prototypes could have been implemented using other software systems. In Figma, drone swarm animations were achieved by duplicating frames and applying delays using the smart animate functionality. This method led to the creation of a large number of frames (utilizing 300 frames for each FIGMA prototype). Certain crucial animations, such as live feed camera, were absent due to the limitations of Figma.

Integrating testing during the initial development phase with the Figma prototypes with a small amount of participants would have facilitated earlier feedback on the UI aspects and allowed for suggestions of potentially better solutions within the prototype itself, rather than only conducting tests with real end-users later on. Further design iterations might have resulted different outcomes, given that the double diamond model allows for many changes.

However, the choice of software for the prototype and whether it was intended to be low-fidelity or high-fidelity were not defined earlier in this thesis. The contents of these prototypes are still sufficient for answering the research questions in the thesis, due to the comprehensive review of existing literature, ongoing collaboration with the HERD research team and the valuable feedback from participants during the user study.

6.3 Implications for Design

I share insights gained from the design and evaluation, offering implications for designing multi-drone interfaces for experienced drone pilots. This intermediate-level understanding is strengthened by presenting this research-backed findings alongside relevant theories and practical examples [43]. These implications align with established research on multi-drone user interfaces. While not entirely novel, the strengthening of these ideas provides positive support for the latest research on human-multi-drone interaction [41].

Pilot adaptability and visual data representation. Some UAV pilots may feel overwhelmed by the stress of managing drone swarms, requiring additional training to effectively engage with the multi-drone system. Other pilots might enthusiastically explore the system’s capabilities and could adapt well to increased complexity. Shneiderman [33] emphasized key principles of data visualization: beginning with an overview, followed by allowing zoom and filtering, and last, providing details-on-demand. User interfaces should offer comprehensive visual representations of data, allowing users to grasp the overall structure or patterns quickly, without overlooking crucial details. This remains an ongoing challenge in this research field: designing user interfaces that meet the essential needs of UAV pilots. The design of this multi-drone system aims to evaluate which types of UI components enhance or detract from situational awareness in search and rescue missions.

Optimizing task management in multi-drone systems. This multi-drone system included a 4-view user interface: Prioritizing the main map view, incorporating with the video stream view, a side menu dedicated to show individual drone status, and a view for giving consent to end the mission [37]. The limited number of views facilitated quick adjustment for UAV pilots with minimal training.
Making sure tasks are completed automatically and providing useful information is highly important, particularly in demanding search and rescue missions [42]. However, even with system messages, notifications, and drone status displays, UAV pilots find it challenging to track all drones. Solely presenting warning text isn’t effective; it should be integrated with UI components for better comprehension. Also, centralizing and saving both events and drone failure messages would enhance comprehension during transitions between these views.

*Enabling on-demand interaction for users.* While UAV pilots could monitor autonomous drone swarms, receive sufficient information about each drone, and watch the drone swarms automatically act in emergencies, it’s crucial to consider incorporating more one-to-one interaction during critical situations [41]. This allows operators to assume control over the drone swarms if needed or of their own interest. As there’s a desire for UAV pilots to still remain the main supervisor of the drones, I propose highlighting the complexity in designing effective solutions, a process which involves balancing mission functionality, drone autonomy and human control.
7 Conclusion

The aim of this thesis was to investigate critical human factors affecting experienced UAV professionals using multi-drone systems, focusing on identifying user interface components that support their missions without overwhelming them with information from the drones or their surroundings.

As a result, two prototypes were developed and successfully tested in a usability test, simulating a challenging SAR mission with many drone events and system messages for UAV pilots to take action while monitoring drone swarms. This test gathered both qualitative and quantitative data, addressing key human factors such as SA, trust, and cognitive workload within this thesis, enabling to address both research questions.

A key finding was the significance of providing UAV pilots with sufficient manual control over each drone within autonomous drone swarms, emphasized by most participants in post-experiment interviews. While many participants highlighted the value of autonomous drone swarms, the UAV pilots indicated a desire to control single drone if further investigation of an detected object was required. Additionally, the final decision concerning the actions taken in response to any drone failure warnings should be made by the UAV pilot.

The majority of participants managed to complete the user tasks using the current implementation, emphasizing the potential of using drone swarms in their work as UAV pilots. Even though the warnings messages were visible (RQ1), there is a need to review how crucial information is represented in the user interface to mitigate the risk of overlooking critical details due to information overload and to increase comprehension. While participants reported significant cognitive workload, variations in SA were seen across different components and SA levels. Furthermore, the study highlighted the importance of sufficient training with drone swarms to optimize performance and build trust to the system during real-life SAR missions.

Heatmaps, studied in relation to increased trust (RQ2), show potential to be an essential tool in demanding SAR missions, but require thoughtful design regarding context for optimal use. They simplify comprehension but there is a demand to vary the use of the heatmap together with the search pattern.

Most requested features included adding thermal cameras and having the warnings more centralized in the user interface. Determining the best practices for presenting UAV data within a drone swarm to reduce cognitive workload and improve situational awareness remains an unanswered challenge. Nonetheless, the thesis suggests that these findings could serve as a starting point for further improvements in multi-drone interfaces.

7.1 Future Work

This study’s limitation lies in the limited amount of end-users, its reliance on qualitative results, and the suggestion for a new iteration. Developing a high-fidelity multi-drone prototype with the most requested features to evaluate how drone swarm information is presented, could be a valuable next step. These early expert insights regarding desired features are crucial for ongoing research on interfaces for real-world SAR missions with drone swarms. To guide future system design and evaluation, mostly qualitative but also quantitative results of this thesis, can be used.
References


REFERENCES


A Appendix for Implementation

A.1 User persona

Figure A.1: Biography of the user persona Emil Larson together with his personality.

Figure A.2: Insights into the user persona Emil’s influences, expectations, and motivations, among other important interests.

Emil Larson

- Age: 40
- Occupation: Drone pilot at the Swedish police
- Education: Engineer
- Location: Stockholm, Sweden

Background

Emil is a dedicated and skilled drone pilot specializing in search and rescue missions within the Swedish police force. With a passion for aviation and technology, he has turned his love for flying and problem-solving into a fulfilling career that directly contributes to saving lives.

Emil’s journey into the world of drone piloting began during his college years when he combined his interest in engineering with his fascination for unmanned aerial vehicles while engaging in volunteer work in missing people organization.

Interests

Emil’s interests are aviation, technology, and problem-solving. He is super interested in how all these things come together and he is always learning about newest drone technology.

When he is not working, he enjoys hiking and photography, often combining his hobbies to capture stunning aerial photos using his hobby drone.

Influences

Emil’s path in life has been influenced by his respect for the first aviators and the people who have made big steps in the drone world.

People like Amelia Earhart and Cro Frank have motivated him to continuously push the boundaries of what’s possible in aerial operations.

Goals

Emil’s primary goal is to make search and rescue missions better by using drones in a smart way in his daily work.

He wants to develop his working skills that can help find people who are missing. This will make rescue teams work faster and have a better chance of saving people.

Needs and expectations

Emil’s key requirements include advanced drone technology for efficient and safe operations, a team of experts to work with during emergencies, and quick access to important information. He hopes his bosses will support him and appreciate the important work he does.

Emil Larson’s career as a drone pilot is a mix of passion, dedication, and a love to make a difference. He remains motivated by the lives he can impact, and he’s happy when his missions go well. He’s always trying to be the best at what he does.

Motivations

Emil’s primary motivation is helping people who are in trouble and their families. The feeling of contributing to a successful rescue operation and bringing answers to worried loved ones is what drives him to go to his work every day.

He also likes that every mission is different and lets him solve interesting problems, and that’s what keeps him motivated.

Pain points and frustrations

Emil’s main frustrations arise from encountering technical issues or limitations in equipment during critical missions.

He’s also concerned about all the rules and paperwork that can make it hard to use drones in some areas.

Any lack of understanding or support from the larger public about the importance of drone-assisted search and rescue can be a little depressing for him.
A.2 Drone Prototype

Figure A.3: The login page of the drone prototype

Figure A.4: The start mission page of the drone prototype.
Figure A.5: System message with a notification due to low battery. Action could be taken to land the drone immediately.

Figure A.6: Video stream view of four different UAVs together with telemetry data.
Appendix for Implementation

Figure A.7: After button press for human detection, a confirmation prompt verifies the drone pilot’s intent to end the mission.

Figure A.8: After button press for emergency stop, a confirmation prompt verifies the drone pilot’s intent to end the mission.
Appendix for Implementation

Figure A.9: Drone side menu with status of all drones.

Figure A.10: Map view of drones returning to home base after detecting a human which potentially is the missing person.
# B Appendix for User Study

## B.1 Human-computer trust scales

Table B.1: The three trust aspects and their corresponding items are evaluated on a 7-point Likert scale ranging from 1, indicating 'Strongly Disagree,' to 7, representing 'Strongly Agree.'

<table>
<thead>
<tr>
<th>Trust Aspect</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ability</strong></td>
<td>- The drone application would be competent and effective at assisting in finding missing persons.</td>
</tr>
<tr>
<td></td>
<td>- The drone application would perform its role of neutralizing stressful rescue situations very well.</td>
</tr>
<tr>
<td></td>
<td>- In general, the drone application would be easy to use when monitoring each drone in a drone swarm.</td>
</tr>
<tr>
<td></td>
<td>- Overall, the drone application would be a proficient tool for monitoring drone swarms.</td>
</tr>
<tr>
<td><strong>Integrity</strong></td>
<td>- The drone application would be truthful in its communication with me through its system messages.</td>
</tr>
<tr>
<td></td>
<td>- I would characterize the drone system as honest.</td>
</tr>
<tr>
<td></td>
<td>- The drone application would keep its system messages.</td>
</tr>
<tr>
<td></td>
<td>- The drone system would perform as expected.</td>
</tr>
<tr>
<td><strong>Benevolence</strong></td>
<td>- I believe that the drone application would operate in my best interest.</td>
</tr>
<tr>
<td></td>
<td>- If I required help, the drone application would do its best to help me.</td>
</tr>
<tr>
<td></td>
<td>- The drone application would be concerned about the status of the drones.</td>
</tr>
<tr>
<td></td>
<td>- The drone application would be concerned about finding the missing person.</td>
</tr>
</tbody>
</table>
Table B.2: Statements evaluated on a 7-point Likert scale from 1 = “Strongly Disagree” to 7 = “Strongly Agree” for the human-computer trust scale.

<table>
<thead>
<tr>
<th>Heat map</th>
<th>Statements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. I think that the drone application is competent and effective with its heat map.</td>
</tr>
<tr>
<td></td>
<td>2. I think that the heat map in the drone application performs its role as trustful very well.</td>
</tr>
<tr>
<td></td>
<td>3. I believe that the heat map has the functionality I would expect from a drone application.</td>
</tr>
<tr>
<td></td>
<td>4. I can always rely on the drone application for its heat map.</td>
</tr>
</tbody>
</table>

B.2 Interview results

Quotes from the post-experiment interviews and observations during prototype utilization.

General Feedback of the Prototypes

“This was the first time flying with drone swarms, so it feels very new. Surely, after a few runs, one would have learned the best way to handle it.”

“I could absolutely consider using drone swarms like this in reality. However, it needs to reviewed how to represent important information.”

“I didn’t feel like I had sufficient control when warnings appeared – it would have been good to be able to choose to send a drone home or immediately with low battery level. This is needed to be able to fly in real-life.”

“I felt the choices were emergency landing, when the application suggested that, or to abort the entire mission.”

“Drones should stop when they detect something. One should be able to decide whether they should stop or continue.”

Drone Swarm Monitoring Attention

“Fewer drones to keep track of. - Monitoring four to five drones simultaneously might be manageable.”

“I could follow the drone swarm on the map view based on the system messages.”

“On the second attempt, I tried to focus on reading the system messages. However, I felt that I should have shifted my eye around, but it’s difficult to keep track of everything at once.”
"I can’t explain how I managed to monitor the drone swarms."

"While I was monitoring, I observed the system messages. These messages were effective at indicating when an event had occurred. However, they could easily go unnoticed as they didn’t remain on the screen for long, especially if another warning popped up simultaneously."

Evaluation of System Messages

"It becomes difficult to keep track of all drones, but the application does assist with that."

"It would be nice if the warnings remained until I choose to remove them, maybe in a scrolling log list so that one can go back if unable to read in time."

"To have the warnings more centralized and not spread out, so that one doesn’t need to look around constantly."

"Filter out what information is crucial and what is unnecessary, when there are many drones."

"I had to read messages, even though they were too many, which nearly caused me to miss finding the person. That’s something you absolutely cannot miss; it’s the most crucial aspect of the entire mission."

Heat Map Analysis

"I like it, it would have been good if one could choose to start searching from that point and then create the flight pattern from there. After all, one would prefer to investigate that area first."

"If not for all the drone issues, I would have chosen to focus on watching the heatmap when the drones passed through the map view, but I didn’t have the opportunity to do that now."

"Within our institution, LKP is very important; that point is usually taken as the starting point when determining the search area."

"It’s relevant, but it doesn’t necessarily mean that the person is within that area."

Desired Features Feedback

"By combining thermal and regular cameras should more easily detect people."

"Maybe sound could accompany a warning message."

"Ability to stop one drone manually, to examine closer the object that might be the missing person."

"Being able to pinpoint where the object/person is located."

"Night vision capability."
“Develop different search patterns, e.g., starting from LKP or searching in various sub-search areas.”
“Camera zoom in/out in the video stream.”

**Participant Observation and Visual Cues**

“This drone has low battery, it will most probably return home immediately.”

“Can I see the other drones here in the video stream? Other than these four?”

“It would have been interesting to investigate this a bit more, if I only could manually control a drone to stop at the possible object.”

“If I loose contact with one of the drones in a swarm, will the rest of the swarm take care of the lost drone while I can’t? Or what happens?”

“The warning message alerted me about strong winds. - I am concerned about the drones’ safety and the risk of damage, I want to end the mission. Consequently, I aimed to press the emergency button.”