Chapter 11
Drone Swarms to Support Search and Rescue Operations: Opportunities and Challenges

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Abstract Emergency services organizations are committed to the challenging task of saving people in distress and minimizing harm across a wide range of events, including accidents, natural disasters, and search and rescue. The teams responsible for these operations use advanced equipment to support their missions. Given the risks and the time pressure of these missions, however, adopting new technologies requires careful testing and preparation. Drones have become a valuable technology in recent years for emergency services teams employed to locate people across vast and difficult to traverse terrains. These unmanned aerial vehicles are faster and cheaper to deploy than traditional crewed aircraft. While an individual drone can be helpful to personnel by quickly offering a bird's eye view, future scenarios may allow multiple drones working together as a swarm to reduce the time required to locate a person. Given these potentially high payoffs, we explored the challenges and opportunities of drone swarms in search and rescue operations. We conducted interviews as well as initial user studies with relevant stakeholders to understand the challenges and opportunities for drone swarms in the context of search and rescue. Through this, we gained insights to inform the development of prototypes for drone swarm control interfaces, including both technical and human interaction concerns. While

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drone swarms can likely benefit search and rescue operations, the significant shift from single drones to swarms may necessitate reimagining how rescue missions are conducted. We distill our findings into five key research challenges: visualization, situational awareness, technical issues, team culture, and public perception. We discuss initial steps to investigate these further.

11.1 Introduction

The Danish Emergency Management Agency (DEMA)[1] engages in missions to protect the public in emergency situations. This includes the search and rescue of people in distress and responding to various situations of increased danger to the public. The equipment DEMA uses to support their missions include highly specialized technologies, tools, and custom vehicles. DEMA, as with other national emergency management agencies, is often first movers in utilizing new technologies and appropriating them into their processes and practices.

An example of such specialized tools that have recently become available is drones. With the falling costs of professional quality drones and improved ease of use, drones have experienced increased adoption by many law enforcement and emergency management agencies. These flying robots are used to carry payloads that gather data, such as cameras for surveillance, microphones, and thermal sensors, as well as active payloads to affect crowds such as a lights and loudspeakers (Engberts and Gillissen 2016). In Denmark, the emergency services have three dedicated drone teams that can be deployed within minutes (Beredskabsstyrelsens droneberedskab 2020; https://www.brs.dk/da/redningsberedskab-myndighed/assistance-fra-beredskabsstyrelsen/beredskabsstyrelsens-ressourcekatalog/sarligt-materiel/droner/). Furthermore, in 60 Danish municipalities, various DEMA personnel are trained to utilize drone technologies in their missions. This primarily involves intelligence gathering, such as observing a fire from above to identify safe areas to direct firefighters or searching a large field with a thermal camera to locate a lost person in distress. Drones are often utilized in conjunction with manned aircraft (helicopters), primarily in maritime search and rescue (SAR). Helicopter-based search is slow, expensive, and requires cross-organizational coordination. Increasingly, drones have been used together with artificial intelligence (AI) and computer vision technologies to provide automated support for emergencies, for example, to provide AI capabilities to analyze thermal imagery directly on a drone to detect forest fires (https://www.robotto.ai/fire). The technology can scan a large area and build a map of the fire. Subsequently, based on the identification of hot spots and weather conditions, it can predict how the fire will move, enabling firefighters to take the appropriate positions to ensure their safety and make decisions that help extinguish fires quicker.

[1] https://www.brs.dk/en/

While this type of semi-autonomous use of single drones provides new abilities to firefighting, recent developments in controlling multiple drones as a swarm may enable even faster coverage and assessments of large areas. Drone swarms for search and rescue hold potential to reduce the time it takes to find a person in distress by covering a large area very quickly and deploying a range of sensors, including visible light and thermal cameras, among others. However, very little is known in relation to the integration of these drones into the working practices of emergency response teams. This includes the user interfaces for controlling and managing a drone swarm, but also the protocols for engagement, as well as the interaction with other parties in the airspace. There has been considerable attention in research on how people respond to socially interactive robots (Fong et al. 2002, 2003), and the early examples of social interaction with robots involved swarms, yet most of the research exploring human interactions focus on humanoid robots.

In this chapter, we describe initial findings from interviews with the Danish Emergency Management Agency in relation to the prospects of using drone swarms for search and rescue. We group our findings into five key research challenges: visualization, situational awareness, technical issues, team culture, and public perception.

11.2 Related Work

11.2.1 UAVs for Emergency Settings

Unmanned aerial vehicles (UAVs) have the potential to support first responders, and the current research space has highlighted this potential. A recent literature survey by Herdel et al. (2022) identified 16 domains for human–drone interaction and found that 'emergency' was the most prominent domain mentioned. UAVs used for emergency situations have the benefit of short deployment time and minimizing the need for human involvement in a hazardous environment (McRae et al. 2019). A UAV can provide visual surveillance of a situation by hovering above the scene and capturing video for the first responders. The video feedback can be used in multiple ways, for example, assessing a developing fire area (Bjurling et al. 2020; Naghsh and Roast 2009; Pham et al. 2017). Autonomous drone-based firefighting tools have begun to hit the market, e.g., the firefighting tools by Robotto,[2] which provides an algorithm for identifying and predicting the behavior of an evolving fire. Similarly, UAVs have also been used in search and rescue missions to find missing people in various conditions (Arnold et al. 2018; Karaca et al. 2018; McRae et al. 2019; Silvagni et al. 2017). A common challenge when using UAVs in SAR is that the team does not find the missing person due to features in the terrain that may obstruct visibility from above. Current research has aimed to automate visual detection by clearly highlighting on

[2] https://www.robotto.ai

the video feed when a person has been found (Goodrich et al. 2008; Mishra et al. 2020; Scherer et al. 2015).

11.2.2 UAV Swarm Behavior and Control

UAVs are mostly piloted individually by one operator, but research is looking at developing algorithms that allow for an autonomous swarm of drones. Compared to using a single drone, a swarm can cover a larger search area faster in a SAR mission, increasing the possibility of finding a missing person.

Current research has explored ways to exercise control over a swarm without resorting to low-level motor commands. Swarm behavior often takes inspiration from animals such as bees, birds, and fish (Hocraffer and Nam 2017). Research has also started to explore the possibility of incorporating a leader among the drones (Kerman et al. 2012; Kolling et al. 2016). Having a leader requires the operator to only focus on a single drone, with the other swarm members adjusting their course automatically. There are various examples of drone controls, such as the basic *selection* of one or more drones to view status, issuing low-level commands such as movement or camera adjustments, or more high-level mission priorities and search pattern selection. In terms of automated search patterns, *spiral* patterns direct the swarm to search an area expanding from a point, and *scatter* patterns disperse the swarm in all directions (Arnold et al. 2018; Kolling et al. 2013). Furthermore, *beacon* controls are used to direct the swarm by attracting the UAVs to high priority areas or by repelling the UAVs from areas that they should not enter (Kolling et al. 2013).

11.2.3 User Interfaces for Human–Swarm Interaction

Controlling one drone is very different from controlling multiple drones simultaneously and potentially requires different ways of interacting. In contrast to the operation of one drone, a swarm potentially requires the operator to divide their attention among multiple drones.

Despite the aforementioned advantages of drone swarms, some disadvantages make it difficult to implement UAV swarms in SAR. One of the biggest challenges for the operator is to maintain *situational awareness* (SA). Studies have shown the importance of only displaying key elements to reduce the amount of visual clutter on the screen (Agrawal et al. 2020; Rule and Forlizzi 2012; Soorati et al. 2021). Having only the most crucial information clearly and concisely available will help the operator to make appropriate decisions while minimizing the chance of errors.

11.3 Interviews and Prototype Evaluations

We conducted interviews with emergency services personnel who already use single-drone systems for search and rescue in order to investigate the challenges and opportunities for drone swarms in the SAR context. Additionally, we conducted evaluations with initial prototypes to stage conversations about how drone swarms could support SAR missions and gathered input relating to the features and functions of future systems. The participants were two senior sergeants, one of whom is responsible for drone-related training and official procedures, while the other is the main person responsible for unmanned aircraft systems (UASs) in the organization.

We began with a review of documentation shared by our participants that explained the current usage of drones during emergencies and SAR missions. Following this, we held a video interview to discuss typical missions and their ideas for drone swarms. We then developed an interactive prototype platform that supports typical mission tasks, including launching and landing drones, selection and movement of single or multiple drones during flight, and selecting an area on the map to contain the search. The prototype also supported advanced swarm concepts, including leader/follower and beacon controls. The system was built using Web technologies and utilized the same drone platform used by DEMA. We brought the prototypes to the DEMA training college, where we conducted the interviews and evaluations. Upon arrival at the DEMA training college, the personnel walked us through their specialized drone support vehicle and explained its components as they set up and flew a short demonstration mission at the campus. Each drone is controlled using a dedicated pilot with a DJI smart controller, as shown in Fig. 11.1.

Fig. 11.1 DEMA drone pilot using the DJI smart controller for controlling a single drone

Fig. 11.2 DEMA drone pilot using the DJI smart controller for controlling a single drone, with the video feed shown on the large screen in the support vehicle

For the demonstration, the pilot flew the drone around the campus and explained the typical process of orienting to the emergency situation and working with the team to scan the live video feed shown on the large screen in the support vehicle, which can be seen in Fig. 11.2.

Following the demonstration, we invited the two participants to experiment with the prototypes we developed for swarm visualization and control. These prototypes were developed to run on a tablet connected wirelessly to multiple DJI flight controllers.

While the prototype could be used with an unlimited number of physical drones, for the demonstration, we utilized two physical drones. This provided the feeling of controlling multiple drones without using low-level controls they would normally use with the provided DJI smart controller. The user interface provides a plan view map of the area (shown in Fig. 11.3) and enables touch interactions to launch and land drones, to select and move drones, and to create virtual beacons to attract and repel drones, among other swarm commands.

We encouraged our participants to be critical of the prototype and invited them to consider themselves as co-designers of the system. Hence, we asked them to vocalize both positive and negative thoughts about the prototype, as well as their ideas for ways to improve the system.

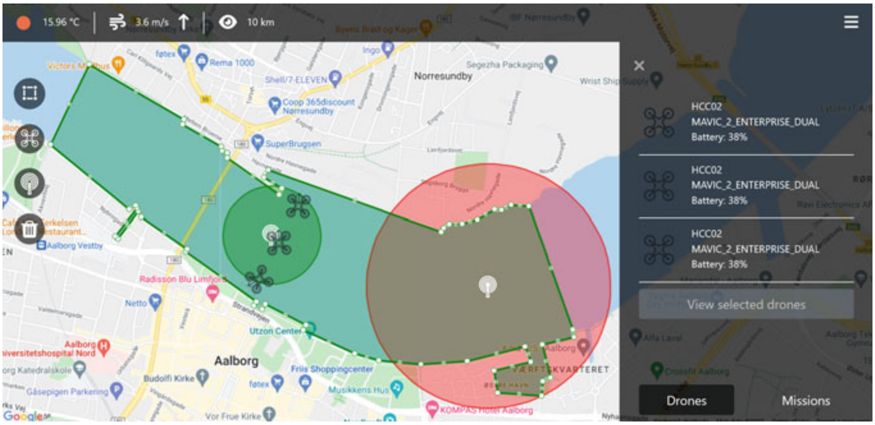

Fig. 11.3 User interface of the prototype. The area shown is the Limfjorden in Aalborg, Denmark. A fence is drawn to contain the swarm, and virtual beacons are placed to influence the search area

11.4 Five Research Challenges

The interviews with the emergency services personnel, our observations, and evaluation of an early prototype have revealed surprising tensions and concerns across a broad range of topics. In this section, we present the key topics that came up in our review of the literature and the interviews as five key research challenges for drone swarms in search and rescue operations. These challenges are visualization, situational awareness, technical issues, team culture, and public perception. We discuss initial steps to investigate these further.

We are aware that these challenges are not an exhaustive list and that there are similar efforts to take a holistic approach when developing SAR systems with drones. The US Coast Guard suggests that such systems be designed not just to satisfy technical requirements, but should be "evaluated and employed as an entire system" (UAS for SAR 2016).

11.4.1 Visualization

From our survey of existing SAR interfaces, we observed a wide variety of ways to present information. A 2D map view is often used (Agrawal et al. 2020; Rule and Forlizzi 2012; Soorati et al. 2021), and the prototypes were designed using these as models. For the design of such expert systems, there is a challenge in deciding which features should be supported and how the information should be presented. Should there be, for example, user selection of presentation style, mode selection, or efforts made toward a standardized way of representing objects and environmental characteristics? Similarly, how should the suggestions from predictive and other advanced AI features be presented? How do colors, symbols, etc., carry across countries and cultures in international operations? The DEMA drone pilots use the 'mapping missions' in the pilot application that comes standard with the enterprise drones[3].[3] The visualizations in the pilot app are not intended for SAR missions, but rather for real estate inspections and construction site documentation purposes. The application is simple and easy to use; thus DEMA has chosen to use the features that are helpful for their work, yet they have shared aspirations for an application built with SAR in mind. The visualizations they discussed go beyond the simple streaming of video and included a desire for the planning of missions and automation.

The two senior sergeants stressed the importance of having a system that was extensive yet simple to use. While they thought the presented prototype was straightforward, they feared it would become cluttered and difficult to use over time when crucial features were implemented. This is a pressing matter as there are different levels of experience and technical skills among the SAR team members. Therefore, when developing prototypes for them, it is essential to ensure simplicity and impor tant to involve less technical members of SAR missions to study the struggles and needs they face in completing their tasks efficiently.

11.4.2 Situational Awareness

In our study, we explored how advanced swarm control interfaces might impact situational awareness. We explored ways to provide predictive support to emergency personnel in which AI techniques identified possible victims and suggested a best course of action of the SAR team. It became clear that the most effective swarm interfaces would provide a balance between showing only partial details of each drone without overloading the pilot with visual indicators. Balancing the number of information elements and the form in which information is represented is an important challenge for the design of any complex interface (Oury and Ritter 2021). By adopting a user-centered approach, we have uncovered unique aspects relevant to the interfaces for supporting SAR with drones that require deeper investigation.

The interviews helped to reveal fundamental shifts in the way the operation is conducted now with single drones compared to a swarm and initial indications as to what the operator should devote their attention to. An example that illustrates this relates to the video feed from the drone cameras. The senior sergeants from our study explained that they originally had the expectation that the camera feed of all the drones would always be displayed at all times, and that the feed would have an alert indicator displayed if something of interest is found so that the operator could decide if it should be inspected more closely or ignored. Currently, a separate person who is not the pilot watches the live video feed; however, in the future imagined system with multiple video feeds, it is not certain how many simultaneous video feeds a person can realistically observe, even with the help from the alert indicator.

[3] https://youtu.be/92RgLBJcViI.

Future studies could determine if it is feasible for a person to continuously monitor multiple drone feeds and the effect this might have on their situational awareness.

One of the senior sergeants expressed his uncertainty about using a multi-drone system for SAR as it would introduce more information for a person to process. He raised the concern that the system should have some level of automation that could alleviate responsibilities from the user. Various new questions arise: Is it necessary to always display the video feed from each drone? How will the roles change among the SAR team members to work together and support the operation? The ambition of the DEMA professionals is that if a partially automated system could detect a person through the camera feed, it could be sufficient for the operator to view a feed only when a potential victim or target has been identified. A significant problem with this proposition is the fear of false negatives and the risk of missing something that a human would notice. To implement such a system, it should therefore undergo rigorous testing and evaluation to ensure that it can effectively be used alongside or as a substitute for human image processing. The culture of the SAR team seems to welcome the use of effective technology tools to aid their missions; however, accepting an autonomous system for critical tasks is a new frontier that we are exploring in the ongoing research and development.

11.4.3 Technical Issues

There are various technical challenges concerning the drone, the operator, hardware, and software. This includes, but is not limited to, sensors, communication technologies, computer vision, predictive techniques, and algorithms for controlling the swarm in a safe and efficient manner.

SAR missions can occur in harsh terrain and weather conditions. It is, therefore, a requirement for the devices to be sufficiently robust. It is also important that when a piece of equipment fails, it does not delay or interfere with the mission. If a system could be synchronized across multiple devices, it might be possible to pick up a backup device and instantly resume a mission if a device fails.

From our interview with the two senior sergeants, we found that a large part of SAR missions is spent determining which areas to search. This choice is affected by multiple factors, such as police information, as well as specific targets of value such as rivers. With multiple drones, it is more challenging to plan a route that would be appropriate for drones to take. An algorithm that suggests a course of action based on both mission and terrain-specific information could significantly help the SAR team plan and prepare a SAR mission.

When working with drones in SAR missions, the drone team instantaneously analyzes the video feed that the drones capture. However, from our initial interview with DEMA, we were informed that it is challenging for the drone operator to maintain focus, especially if they are looking at a repetitive pattern such as a field. For a drone swarm to be useful, it is necessary to develop a computer vision system that automatically detects if something has been found and alert the operator clearly and effectively.

11.4.4 Team Culture

The processes and procedures currently in place have been developed over time and tuned such that the team works tightly in unison and knows what to expect. This is vital during time-critical operations. Therefore, introducing drone swarms is not as straightforward as replacing one helicopter with a swarm of drones. The team structure will likely need to adapt with various new roles and responsibilities. The helicopter pilot and passenger are partially replaced by unmanned aircraft, but there is an increased demand in maintaining, deploying, and configuring the hardware and software and supporting it in the field. How should the transfer of responsibility from personnel that is distant to the local personnel take place and what practices will emerge? Field trials and exercises are needed to gain input from the teams and to explore alternatives.

Each SAR mission often involves professionals from multiple agencies, including police, military, and firefighters, among others. Currently, SAR missions start with a call made to the police. The police call in the DEMA resources to begin the search, providing initial details to the SAR team via telephone while the vehicles are en route to the scene. The interviewees expressed that this process works very well; however, they also imagined that a robust future system could allow the police to annotate a digital map to suggest initial search areas and to provide other key details more quickly. They described that in the initial annotations, the police could mark up areas best suited for the drones and other areas that are best suited for search dogs and personnel. This raises a lot of questions about which personnel would have access to view and explore the map and whether multiple personnel should edit and annotate simultaneously.

The military also plays a role in SAR missions, utilizing a specialized helicopter with a pilot and spotter who scans the area below. In current practice, there is direct voice communication between the helicopter and drone operator to coordinate search areas and to ensure that the drones and helicopter operate with a safe distance from each other (no closer than 200 m). In the future, with swarms of drones, there will be some level of automation. The swarm could be programmed to always maintain a safety distance to stay clear of the helicopter. To ensure the highest level of safety, it is presumed that a human drone operator remains in control and can override any movements of the swarm—and perhaps the helicopter crew should also be equipped with a view into the system so that they can understand the swarm's movements, and perhaps override the system directly and force the swarm to land should there be any imminent danger. Future studies together with the various teams are needed in order to maintain trust and understanding.

11.4.5 Public Perception

As with any novel technology, public perception and acceptance is important for the eventual adoption of this technology. Drone swarms need to provide a qualitative improvement to SAR and not just a reduction in costs. Managing the public perception and interest is important in the early stages to enable the maturing of the technology and techniques. Furthermore, the public will begin to see swarms of flying machines during emergencies, raising the question as to how this will be perceived. How will the public react to a swarm of drones flying in their area? Are there ways to communicate from the drones to the public and bystanders what is happening and what they can do to help? For example, establishing cultural symbols for bystanders to 'stand back' might be critical during operations.

Drones that actively search in public spaces are not commonly seen in residential areas in Denmark and are likely not perceived the same way as emergency vehicles such as ambulances or police cars. Studies have also shown how drones specifically used in residential areas can cause residents discomfort because of the uncertainty of their purpose and whether they can cause any harm (Bajde et al. 2017; Lin Tan et al. 2021). However, knowing that the drones are used in the context of an SAR mission is likely to be a more accepted usage of drones. It would be relevant to examine possible ways to signal to the public that drones are actively involved in an emergency, for example, by taking cues from existing emergency vehicles such as color, sound, and light signals. Taking inspiration from research on non-verbal communication with robots (Bethel and Murphy 2008), affective expression could be explored in future studies through managing the social distance between drones and people and through the use of visual and auditory cues. Drones are relatively new in the public sphere and beginning to influence cultural practices. The two DEMA senior sergeants told us that SAR inside residential areas provide some of the most challenging scenarios. This is due to multiple factors, including the presence of residents, difficult heat signatures from thermal cameras, and heightened legislation. While DEMA has the right to fly beyond standard flight rules if they deem the increased risks to be acceptable, it still does not solve the problem of the increased difficulty of the search. Drone software could play a larger role in increasing the effectiveness of drones in SAR missions in residential areas. It would be relevant for the drones to plan routes that would avoid people by, for example, exclusively flying over rooftops and avoiding flying above uninvolved pedestrians. More attention is needed to ensure that interactions with people in public contribute to feelings of safety, trust, and understanding of the drones' intentions.

11.5 Conclusion

In this chapter, we set out to share our experiences with an ongoing project in which we are designing user interfaces for controlling drone swarms for search and rescue. We conducted interviews with emergency services professionals and initial user studies with drone swarm prototypes in order to understand some of the challenges and opportunities. We learned about the current practices and procedures that are in place when utilizing a single drone to assist in SAR missions. It became clear that a more holistic view is necessary when designing in this context. Moving from manual control of one drone to automated swarms of drones will need technical advances, but also a careful consideration and involvement of the professionals. We provided highlights from the studies grouped into five key research challenges: visualization, situational awareness, technical issues, team culture, and public perception. We discussed initial steps to investigate these further. The system we are building together with DEMA is a very specialized assistive technology. We envision that it could be a tool that will help balance the mental workload of the operators while providing situational awareness. While a well-designed technical solution may be needed, our investigations thus far have shown that more focus is needed to understand the people, processes, and culture of the emergency services teams in order for swarms of drones to provide real value to search and rescue operations.

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