The HERD Project

Human-Multi-Robot Interaction in Search & Rescue and in Farming

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The HERD Project: Human-Multi-Robot Interaction in Search & Rescue and in Farming

Anders Lyhne Christensen*, Kasper Andreas Rømer Grøntved*, Maria-Theresa Oanh Hoang†, Alexandra Hettich‡, Niels van Berkel†, Mikael Skov†, Alea Scovill§, Gareth Edwards§, Kenneth Richard Geipel¶, Lars Dalgaard‖, Ulrik Pagh Schultz Lundquist*, Ioanna Constantiou‡, Christiane Lehrer‡, Timothy Merritt†

*University of Southern Denmark, †Aalborg University, ‡Copenhagen Business School,
§Agro Intelligence ApS, ¶Robotto ApS, ‖Danish Technological Institute

***Abstract*—Large-scale multi-robot systems have numerous potential real-world applications. It is, however, still unclear how a human operator can effectively engage and control a system composed of multiple autonomous robots, especially in unstructured and outdoor environments. This paper reports on ongoing work in the project HERD — Human-AI Collaboration: Engaging and Controlling Swarms of Robots and Drones, in which we focus on two concrete use cases from industrial partners, namely farming and search & rescue. One of the industrial partners, Agro Intelligence ApS, currently sells autonomous farming robots, while the other, Robotto ApS, develops autonomous drone-based monitoring solutions for emergency responders. Both partners aim to scale their technologies to multi-robot/multi-drone operations. In this paper, we present the two use cases, their differences and similarities, challenges and preliminary results.**

***Index Terms*—human-robot interaction, search and rescue, agricultural robotics, swarm robotics**

I. Introduction

Robots and drones take on an increasingly broad set of tasks, such as the autonomous farming robot by Agro Intelligence (AgroIntelli) and the drone-based emergency response systems from Robotto, see Fig. 1. Currently, however, such robots are limited in their capacity to cooperate with one another and with humans. In the case of AgroIntelli, for instance, only one robot can currently be deployed on a field at any time and is unable to respond effectively to the presence of a human-driven tractor or even another farming robot working in the same field. In the future, AgroIntelli wants to leverage the potential benefits of having multiple robots working in parallel on the same field to reduce time to completion. A straightforward way to achieve this is to partition the field into several distinct areas corresponding to the number of robots available and then assign each robot its own area. However, such an approach is inflexible and requires detailed a priori planning. If, instead, the robots were given the task collectively, they could potentially coordinate their operation on the fly and adapt based on local conditions to achieve optimal or near-optimal task performance.

Similarly, Robotto's system architecture currently requires one control unit to manage each deployed drone. In large-area search scenarios and operations with complex terrain, the coverage provided by a single drone is insufficient. Multiple drones can provide real-time data on a larger surface area and from multiple perspectives — thereby aiding emergency response teams in their time-critical operations. In the current system, however, additional drones each require a dedicated operator and control unit. Coordination between operators introduces an overhead and it can become a struggle to maintain a shared understanding of the rapidly evolving situation. There is thus a need to develop autonomous drone-to-drone coordination and interfaces that enable high-level management of a multi-drone system from a single control console. The complexity requires advanced interaction mechanisms to keep the data actionable, simple, and yet support the critical demands of the operation. This challenge is relevant to search & rescue (SAR) as well as other service offerings in the roadmap, including firefighting, inspections, and first-responder missions.

The move to multi-robot systems raises a whole new set of challenges compared to the current paradigm where there is a one-to-one mapping between operator and robot. The operator must be able to interact with the whole system as a single entity to set mission priorities and constraints, and at the same time, be able to intervene and take control of a single robot or a subset of robots. An emergency responder may, for instance, want to take control of a drone to follow a civilian or a group of personnel close to a search area, while a farmer may wish to reassign one or more of the farming robots to another field.

In the HERD project, we selected two application domains, SAR and farming, which have several common characteristics and distinct differences. Both domains involve time-sensitive missions carried out across geographical areas with planning conducted by domain experts. Both domains contain inherent stochastic elements, such as weather conditions. In both cases, the robots/drones are mobile and have substantial onboard sensor systems and processing capabilities and must collaborate with other robots/drones and humans. To distinguish the domains, the SAR drone operating space is in the air with a focus on a chaotic and rapidly evolving emergency, while the agricultural operating space is terrestrial and involves longer timescales with more complex planning and coordination with

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(a) (b)

Fig. 1: The robot/drone platforms used by the industrial partners: (a) the autonomous farming robot from AgroIntelli, and (b) drone with software from Robotto for emergency response

a variety of co-located equipment and personnel.

II. Methodology

In the HERD project, we divide our overarching goal of enabling end-users to engage and control multi-robot systems into four different, but closely related challenges:

- **Pre-operation and on-the-fly planning:** Prior to a mission, the user should be able to provide a plan or a specification of the mission to be carried out by the multi-robot systems, such as the task area, mission priorities, and constraints. A plan may contain a significant amount of detail, such as in the case of farming where the robots must precisely follow crop rows, or only a rough initial specification of the search area in a SAR operation. In both cases, however, the end-user must be able to adjust the plan on the fly, e.g., change the turn radius of farming robots or modify search priorities in a SAR operation.
- **Situational awareness:** To be able to trust and use a multi-robot system, the end-user needs to have confidence that the system is operating as intended and that it will continue to do so. This often requires that the user understands what the system has done, what it is currently doing, and can approximate what the system will do in the future [1].
- **User intervention:** Users need to be able to intervene and take control of parts of the system, and to dynamically add and remove units. An emergency responder may, for instance, wish to take manual control of a drone after it has detected a heat signature to confirm whether or not it originates from a person in distress. When a user is manually operating a single unit or a subset of the units in the multi-robot system, the remaining robots must continue to operate correctly and safely.
- **Workflow and governance:** The use of multi-robot systems changes workflows and roles in the end-user organizations. When the current one-to-one relationship between operator and robot shifts to a one-to-many relationship, some existing roles will become redundant, while new roles will be created, e.g., related to creating plans and monitoring the systems during operation. In the project, we will investigate and design governance structures that enable efficient interactions between humans and multi-robot systems from an organizational perspective.

To develop and study methods that enable end-users to engage and control multi-robot systems in real-world outdoor environments, we conduct research on planning, multi-agent systems, and human-robot interaction, combined with frequent discussions and prototype evaluations with end-users throughout the project. Our two use cases and preliminary results are presented in the two subsequent sections.

III. Use case: Multi-robot field operations

Advances within the field of agricultural robots have made it possible for Unmanned Ground Vehicles (UGVs) to perform a variety of tasks, including precision farming. Many farming tasks are monotonous and repetitive, such as seeding, weeding, and herbicide spraying which in recent years have seen much attention in both research and industry [2]. A decrease in available human labor in agriculture has created a market for autonomous robotic solutions [3], such as the general mobile farming robot produced by AgroIntelli, see Fig. 1a.

AgroIntelli's solution relies on a proprietary centralized coverage planning algorithm that creates static plans for a single robot, see Fig. 2. Multi-robot systems in agriculture present some general challenges, such as (i) creating user interfaces (UIs) that are easy to learn and master, (ii) supporting the farmer in creating and adjusting complex field operations, and (iii) developing robust and effective multi-robot planning algorithms. The unstructured outdoor environment can present situations not foreseen during the planning process, which in turn can decrease performance. Issues must therefore be resolved as quickly as possible whether autonomously, through user intervention, or a combination of the two. Examples of unforeseen situations are, a fallen branch from a tree at the edge of a field, a newly formed wetland, or a malfunctioning implement, which often require manual intervention. It is important that the operator is aware that an unforeseen event

Fig. 2: A section of AgroIntelli's dashboard displaying a plan and live progress of an ongoing operation

is likely to occur or has already occurred. When dealing with multi-robot systems, it is vital that the user has a good understanding of the state of the operation and has the means to take action against or mitigate issues compromising performance or safety. Visualizing a highly complex state of an operation while minimizing the cognitive load of the operator is one of the main challenges addressed in the HERD project.

Research on route optimization for autonomous robot farming is mostly focused on static planning methods, such as the vehicle routing problem (VRP), which is a special case of the traveling salesperson problem [4]. VRP has been generalized to farming tasks for both single-robot systems and multi-robot systems [2], [4]–[7]. One of the most important aspects of a system for real-world use is how it is operated and maintained by the user. In the project, we will concurrently develop and fine-tune the UI for human-multi-robot interaction and the multi-robot control algorithms through an iterative process. The iterative process combined with periodic feedback from end-users will help ensure the effectiveness and usability of the developed solutions in real-world scenarios.

IV. Use case: Multi-drone search & rescue

Progress within the field of drone technology has provided a general platform for sensing for both civil and commercial use, which has pushed the capabilities of what single-drone systems can achieve. Our work in the HERD project focuses on enabling the use of multiple autonomous Unmanned Aerial Vehicles (UAVs) for SAR operations in close collaboration with Robotto and The Danish Emergency Management Agency (DEMA). SAR operations often have a duration of several hours. Due to the limited flight time of UAVs, which is currently a few tens of minutes, an autonomous multi-robot system needs to take the UAV flight time into account during pre-operation and on-the-fly planning [8]. The batteries will eventually deplete and have to be replaced or charged.

A SAR operation's success is highly dependent on elapsed time, and it is essential that the available resources are distributed efficiently to minimize the time of the SAR operation [9] as the chance of the distressed person surviving decreases rapidly with time [10]. In our ongoing work, we are focusing on minimizing the SAR operation time by enabling the operator to effectively configure and control the search effort for multiple, autonomous drones.

In SAR operations, the search strategy is vital and will change from one mission to another, either based on operator preferences or the strategy might change based on any available knowledge about the distressed person's condition, the search area's geographical topology, and so on. It is therefore important that the operator has the right tools to easily alter the strategy of the autonomous UAVs, collectively, individually, or by taking manual control of a single UAV.

SAR operations are often conducted in unstructured, natural environments, and priorities can change frequently based on new information received from external sources and on the results of the ongoing search. The new information can lead to modification of the search area, the direction of search, or even the search strategy [11]. In our ongoing work, we are developing a UI that enables the operator to efficiently change the behavior of the multi-drone system and respond to the flow of information about the complex state of a SAR operation. This will require multi-robot path planning algorithms that are highly flexible and can accommodate the variability of natural environments, frequently changing task specifications, and the dynamic removal and addition of UAVs to the search effort.

The search area is commonly specified as a polygon, along with any interior no-fly zones. The area is divided into non-intersecting regions called *cells* using a decomposition technique [11]–[13]. A common method for creating coverage plans of a polygonal area is the boustrophedon/snake pattern [12], and has been widely used for pre-operation planning in SAR operations [8], [13], [14]. This search pattern is especially attractive because it is easily understandable for the operator and can be optimized for quad-rotor UAVs by minimizing the number of turns in the coverage pattern, which effectively reduces the time of the operation [15]. An alternative to these methods is formation flying which is another well-known technique in swarm robotics [16] and search & rescue [17], and is efficient for covering a large area continuously and provides robustness to failures of individual agents within the swarm. Our work focuses on designing dynamic multi-drone planning and coordination algorithms that are robust to changes in the environment and in the number of UAVs participating in the search, while still providing the operator with situational awareness.

Our current prototype allows the user to see active drones on a map and to allocate multiple drones to the same destination. We conducted a pilot study where two senior sergeants from

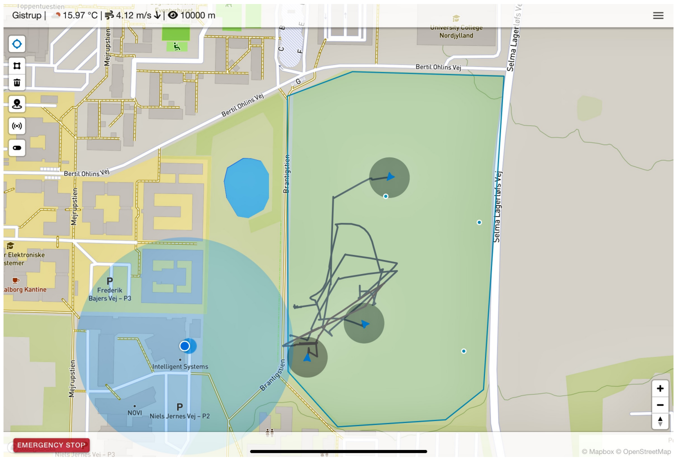

Fig. 3: Early UI prototype for multi-drone control in SAR operations

DEMA provided their feedback on the prototype, and Fig. 3 is an iteration of the UI based on their feedback. Initial results are presented in [18], with findings that suggest some level of UAV autonomy beyond search is needed to safely incorporate our solution in a real-world SAR environment, as independent actors such as helicopters and other search personnel will be present in the search area. One of the senior sergeants also raised concerns about an operator's ability to reliably examine video data from multiple drones in real-time, which could lead to load-induced image blindness. In order for a multi-drone system to work well, we will study how to provide situational awareness of not only the drones' behavior, but also determine when and in what way to process and present the camera feeds [19], [20].

V. Conclusions

In this paper, we have discussed our ongoing work on enabling end-users to effectively engage and control multi-robot systems in real-world outdoor scenarios in the context of the HERD project. The HERD project started in November 2021 and will finish in July 2025. By the end of the project, we expect to have conducted multiple field experiments with our industrial partners using the technologies developed in the project along with their hardware platforms. The field experiments are intended to demonstrate the effectiveness of the solutions and to identify additional improvements. We expect the solutions developed in the project and findings from the evaluations will have a direct impact on the products and services of the partner organizations and lead to increased efficiencies in agriculture and more effective search & rescue operations.

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