Human-UAV Collaborations in the Human-On-the-Loop Emergency Response Systems

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Abstract

The use of autonomous unmanned aerial vehicles (UAVs) for emergency response scenarios, such as fire surveillance and search and rescue, offers great potential for societal benefits. UAV onboard sensors such as GPS, LiDAR, thermal cameras and AI algorithms for planning and sensing enable them to make decisions and act autonomously in the environment without requiring explicit human control. However, human planning and strategic guidance can enhance the mission outcome. Designing a real-world solution in which humans and autonomous UAVs work as a team in a time-critical environment represents an extremely challenging design problem, that demands a careful balance between trade-offs associated with UAV autonomy versus human control, mission functionality versus safety, and the informational needs of humans versus UAV autonomy in executing the mission. This dissertation explores human-centered design solutions for human situational awareness of the UAVs' autonomous activities and for achieving true human-UAV partnerships.

Introduction

A well-known issue in designing a system comprising humans and autonomous agents is to identify how they can collaborate and work together to achieve a mission goal (Sheridan et al. 1998). The challenges in human multi-UAV collaboration include (a) designing User Interfaces (UI) to support humans in maintaining awareness in rapidly emerging scenarios in which multiple UAVs act autonomously, (b) identifying when and how humans should intervene to adjust UAV autonomy levels, (c) identifying how UAVs should adapt and explain their behavior in order to maintain humans' trust in them, and finally, (d) identifying how multiple humans and multiple UAVs can exchange information during a large scale emergency response mission to support information requirements of diverse stakeholders.

This dissertation aims at addressing the current challenges in deploying multiple unmanned aerial vehicles for emergency response, and proposes user centered design solutions to leverage autonomous UAVs as intelligent partners of human rescue teams during emergency response. Endsley previously identified eight common design problems impacting Situational Awareness (SA) (Endsley 2017) and referred to them as Design Demons. My work builds upon these design challenges in the context of Multi-UAV emergency response systems and proposes new interaction techniques enabling humans to maintain sufficient SA of the operating environment whilst advancing bi-directional communication between humans and UAVs.

Approach

In Summer 2019, we conducted multiple participatory design sessions with the firefighters of South Bend to explore scenarios in which UAVs could be beneficial to first response teams. The design sessions produced end-user requirements and guided the initial design of our emergency response system called DroneResponse. The details of the participatory design process, and its outcomes, were published at CHI-2020 (Agrawal and others 2020b). Figure 1 shows a snapshot of the multi-UAV mission in the DroneResponse UI. We use *DroneResponse* extensively in this thesis to evaluate multiple human interaction techniques and to refine the interface iteratively based on our findings. In this thesis, we specifically address the following research questions.

- **RQ1** What design trade-offs arise from explaining autonomy in a multi-UAV environment, and how can these trade-offs be resolved whilst providing sufficient SA to remote operators?
- **RQ2** What communication challenges arise when multiple humans and multiple UAVs collaborate to achieve mission-related goals, and how can we address them through user-centric design approaches?
- **RQ3** How can UAV onboard autonomy models be extended to leverage the intelligence and unique decision-making abilities of humans and UAVs during emergency response missions?

To summarize our research goals, we will systematically study the design challenges in human interaction

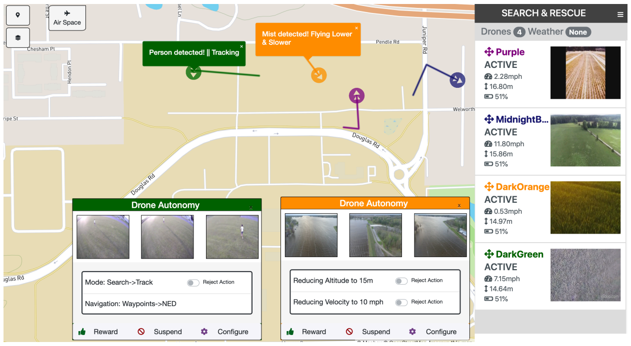

Figure 1: Drones simultaneously adapt their paths and report rationales for their decisions. The Orange drone, for example, detects mist and reduces altitude and velocity to preserve vision.

with multiple autonomous UAVs. In this thesis, we will develop novel interfaces and conduct user studies with UAV experts to evaluate our design choices, and will leverage expert's feedback to iteratively refine our interfaces and propose general guidelines for designing Multi-UAV UIs.

Current Status

RQ1: UAV Autonomy Explanations

Humans supervise multiple UAVs in emergency response missions primarily through information presented in the UI. They need to understand the rationales behind the UAVs' autonomous decision-making so that they are able to judge the correctness of the UAVs' behavior. However, adding too many detailed explanations can lead to the well-known SA design demons, such as 'information overload'. We therefore explore design solutions for explaining autonomous decisions of multiple UAVs to human operators, with the aim of empowering the operators to effectively supervise a HoTL system and intervene when needed.

To this end, we conducted a series of experiments focused upon explanations of the following commonly occurring autonomous UAV adaptions: 1) flying lower and slower in misty weather conditions, 2) tracking a victim, 3) returning to launch due to a mechanical failure, and 4) planning a new path to avoid collision with other UAVs in the mission. Our experiments were supported by augmenting the DroneResponse UI to include explanations of UAVs' autonomous behavior, as illustrated in Figure 1, which shows how multiple UAVs adapt their flights in response to different events and provide explanations to the operators.

Our experiments included both inexperienced and expert UAV operators, and were designed to assess human situational awareness when multiple UAVs explain their autonomous behavior simultaneously. Further, our study examined the impact of explanations when the UAV made an incorrect decision (for example, deciding to track an object that it mistakenly identified as a human victim) on the human perception of the situation and how it affected the Human-UAV collaboration during a mission. We asked MTurk workers and UAV specialists to observe autonomous UAV missions using our UI and to explain their understanding. We analyzed their perception of the mission by using the Situational Awareness Global Assessment Technique (SAGAT) (Endsley 2017) to answer our RQ1, and from their feedback, we derived a set of recommendations for designing interfaces for Multi-UAV systems. My first author paper describing findings of this study is accepted for publication at the Internation conference on Human Computation and Crowdsourcing, 2021 (Agrawal and Cleland-Huang 2021).

RQ2: Human-UAV Team Collaborations

Conducting an emergency response mission involving UAVs requires two-way communication between humans and UAVs (Cleland-Huang and Agrawal 2020), an efficient way to share information across rescue teams, and the ability to visualize relevant scene information that supports the rescue team.

When UAVs are used in search and rescue operations, the rescue teams examine aerial video streams to gain improved situational awareness and to look for critical information, such as clothing, log jams blocking the flow of water, or even civilian cars on the banks of the river. However, clearly communicating this information across multiple rescue teams – especially using verbal communication, is very challenging due to the difficulty of describing geographic coordinates. Therefore, we are developing a framework which automatically calculates the Geo-location of any identified point of interest (POI) in the aerial video streams. We are utilizing the paradigm of Location-based Augmented Reality (AR) to Geo-spatially tag scene information on aerial video streams in real-time. Our framework includes three different interfaces: Flying-AR for marking and visualizing Point of Interest (POIs) such as location of a victim on the aerial video streams, DroneResponse for visualizing POIs on 2D maps providing a spatial summary of the mission, and FirstResponse-AR for augmenting POIs in the first-person view using the AR glasses for the on-scene first responders. In our preliminary tests, We found that Flying-AR can calculate the geolocation of an object based on its image pixel coordinates in the aerial video frame within a radius of 2 meters of its actual location.

Figure 2 shows the overall architecture of our implemented framework and illustrates the flow of information between human interfaces (Flying-AR, DroneResponse, FirstResponse-AR) and UAVs. The design of our framework allows for the distribution of information in real-time to all rescue stakeholders, including UAVs, in a format that facilitates comprehension and actions. As a result, our framework lays a foundation for answering RQ2. We are conducting usability tests, such as User-Experience Quality (UEQ) and System Usability Score (SUS), to study the usability of our framework

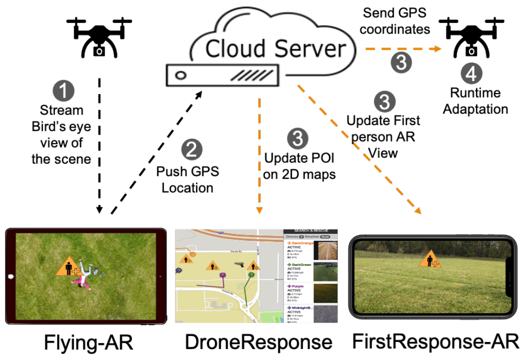

Figure 2: Human-UAV Collaborations: A human marks the victim visible in the aerial video frame via Flying-AR. The framework computes and broadcasts the victim geolocation to other rescue teams and UAVs.

in the real-world conditions. Further, we are collecting feedback from domain experts to refine interfaces for improving Human-UAV team communications and collaborations. A first-author paper describing the interface design and preliminary findings is under review.

RQ3: Extended UAV Autonomy

The UAV autonomy models utilize onboard sensors such as thermal cameras, GPS, Gyroscope, and LiDAR in conjunction with AI-Driven algorithms to autonomously plan and perform their actions without requiring any human support. However, a safety-critical mission such as river search and rescue requires intermittent human intervention in the UAV autonomy, for instance, to respond to changes in the mission strategy. Therefore, We followed a scenario-based approach to augment UAV autonomy models with human intervention, thereby enabling UAVs to adapt their autonomous behavior in accordance with human intentions.

We examined human-UAV interaction in five different emergency response situations, which included *River Search-and-Rescue*, *Defibrillator Delivery*, *Traffic Accident Surveillance*, *Water Sampling* for hazardous chemicals, and *Man Overboard!* to identify patterns of human interventions in the UAV autonomy. Based on our analysis, we categorized commonly occurring human interventions in the UAV autonomy as follows: (1) *Raising or Lowering Autonomy Levels* based on the reliability of the UAVs and human trust upon them, (2) *Sending Feedback or Commands* based on the UAVs' autonomous behavior in response to an event in the environment, (3) Seeking *Rationales* for the autonomous actions of the UAVs, and (4) Providing *Information* about the environment to support onboard autonomy in decision-making. We utilized the identified human intervention patterns for two purposes. First, we presented a human multi-UAV intervention model that formalizes human intervention in the autonomy of the UAV. Second, we developed a process based on a set of probing questions for eliciting and specifying human intervention requirements for multi-UAV use cases. We partially address RQ3 by evaluating our model for a fire surveillance use case in which multiple UAVs leverage onboard thermal cameras to autonomously create a 3D heat map of a building. The study was published at the 2020 Model-Driven Requirement Engineering Workshop (Agrawal and others 2020a).

Future Directions

This dissertation has leveraged simulated environments to explore human interactions with multiple UAVs. However, the real world is far more complex and presents challenging environmental conditions for autonomous UAV operations. To complete the dissertation, I will conduct a series of field experiments based on our previous user studies to: 1) determine the extent to which findings from the simulated environment correspond to the real world, and where needed improve the UI design accordingly, 2) improve the fidelity of simulator study design for future human multi-UAV experiments, and finally 3) learn how factors in the real world such as mission complexity, UAV Autonomy, scale of emergency response, number of UAVs, and environmental conditions impact human situational awareness in the real world using our UIs.

Acknowledgment

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