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Considerations for Handover and Co-working with Drones

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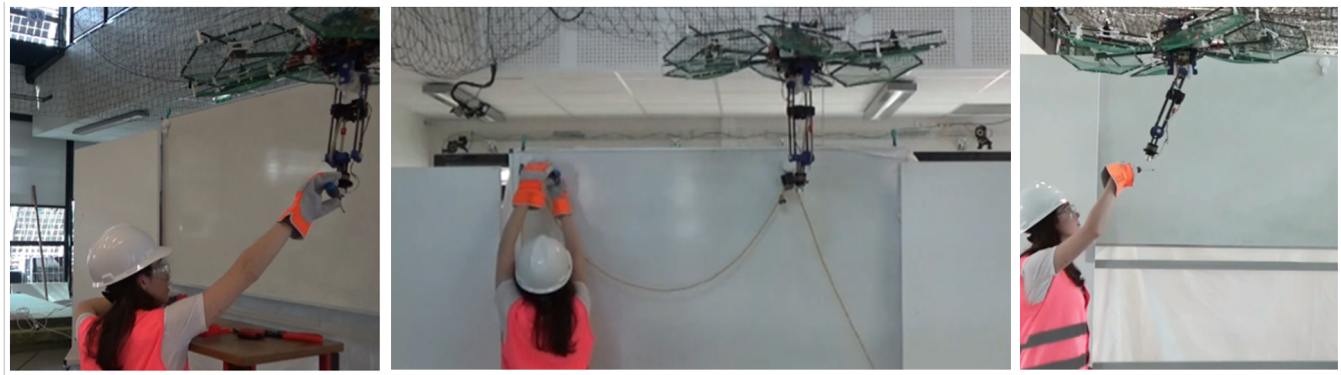

Figure 1: Example interaction scenarios between a user and a co-working drone, as developed in our project: (Left) handover of a tool from drone to human (Center): collaborative hanging of a cable (Right): handover of a tool from human to drone.

ABSTRACT

Recent progress in aerial robotics foresees that flying robots, a.k.a. drones, can support workers in their jobs, such as by performing complex tasks in hard-to-reach places. As they become increasingly autonomous, we envision co-working drones helping human operators in direct collaborative tasks, such as by carrying tools and handing them over to workers at heights, or helping them lift and precisely position structures on construction sites. Yet, much research is needed to support safe close-body interaction between humans and drones. We here propose specific considerations for human-drone collaboration related to such handover, from the drone approaching a person in view of interacting with them at close proximity, to the handover itself, and to the drone leaving. In addition, we present the results of semi-structured interviews with three professionals in this context of human-drone collaboration. This late-breaking report highlights challenges and opportunities fostered by Human-Aerial Robot Handover (HARH).

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CCS CONCEPTS

• **Human-centered computing** → **Ubiquitous and mobile devices**; • **Computer systems organization** → *Robotics.*

KEYWORDS

Human-Drone Interaction; Co-working Drone; Handover; Collaboration; Robotic arm; Cobot

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1 INTRODUCTION

The Human-Drone Interaction community has brought forth a plethora of scenarios [6, 7] requiring close interaction between human and drone. For instance, in search-and-rescue, emergency personnel are confronted with complex situations under time pressure for which drones can be of invaluable help, supporting manual tasks, e.g., helping lift a load or bringing medical supplies; or providing situational awareness [2]. In construction, co-working drones can help people in direct collaborative tasks, such as by carrying tools and handing them over to workers at heights or by helping them lift and precisely position structures on construction sites. Recent progress in aerial robotics foresees that drones will support

human operators in their jobs, such as by performing complex tasks in hard-to-reach places [16, 18]. Yet, for a co-working drone to be an efficient tool and not a burden, it must be designed considering both human and drone constraints [4]. For instance, workers may wear a safety harness, helmet, and gloves and have limited mobility in their tasks; and co-working drones may have limited mobility when co-manipulating structures and/or exchanging tools or devices. Indeed, interacting with a user on the ground, on a roof, or a ladder will present different challenges regarding the drone's position and the exchanged force. We argue that appropriate interaction mechanisms are essential in view of a collaborative task, such as handing over equipment to/from the drone, i.e., Human-Aerial Robot Handover (HARH), or collaboratively transporting and hanging long and bulky objects. We here present initial considerations for handover and co-working with drones.

2 PRIOR WORK ON HUMAN-ROBOT HANDOVER AND CO-WORKING

In any engagement between two agents, the interactors start, maintain, and end their perceived communication with each other [15]. The process of initiating interaction combines both verbal and non-verbal behaviors to support the perception of the connection between the interactors. The non-verbal channel can signal that they have seen each other, provide information about what an agent intends to do and evidence for their presence in the interaction [3, 15]. The handover process is a collaborative joint action where an agent (giver) delivers an object to a second agent (receiver) [9, 11]. In this process, the agents collaborate in space and time to achieve the task effectively, here exchanging the object. The item can be transferred in both directions: drone-to-human or human-to-drone.

Based on prior research in human-human collaboration, it has been shown that the handover process involves coordinated behaviors of both agents at a physical and a socio-cognitive level [17]. The socio-cognitive activities support the decision-making related to the "what", "when" and "where/how" of the interaction. Indeed, the two agents of the handover must agree on the item to be exchanged (i.e., *what*), decide at which moment to start transferring the object (i.e., *when*), and lastly *where and how* to meet to transfer the object. The physical level of the handover consists in the implementation of what the agents have agreed to in their socio-cognitive coordination.

The handover task can be divided into three main phases: pre-handover, physical handover, and post-handover. In the pre-handover phase, two agents (here: human and drone) approach and reach each other while agreeing on mutual aspects of the collaboration. In the approach during the pre-handover phase, the giver moves towards the receiver while carrying the object to be exchanged. When the two agents are at a convenient distance, the reach phase occurs and concludes with both agents being in contact with the object being passed. At this point, the actual transfer is starting (handover phase) and the two agents usually maintain a constant relative pose with respect to one another [17]. Then, the receiver holds the grasped object passed by the giver, and the agents retreat themselves (post-handover). While handover techniques with ground robots such as mobile manipulators have been well studied in the literature [11], research on handover with aerial robots is

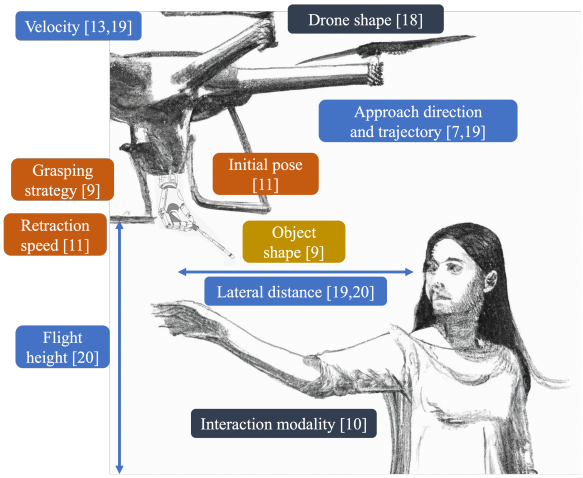

Figure 2: Factors to consider in handover and collaboration between a human and a co-working drone. Each factor includes a reference to prior work. This image was created with the assistance of DALL·E 2.

sparse [1]. In this particular case of HARH, one agent is an aerial robot and the second one is a human worker who shares the same workspace (collocated). The aerial robot is equipped with a robotic arm and hence is capable of giving and receiving the object to (or from) the human partner to successfully perform the handover. In doing so, the endpoint of the robotic arm shall be moved to a reachable and convenient position with regard to the human perspective, especially if the human has limited movement (e.g., standing on a roof or against a wall on a ladder). Moreover, the object should be handed over in the most ergonomic configuration from the human standpoint. Thus, that location shall prevent the user from attaining body configurations, which may result in discomfort during the object transfer. We present a non-exhaustive set of handover and co-working considerations for drones with their human partners. These considerations have been studied in the literature either for robotic handover or human-drone interaction, but not yet in HARH. We propose the following considerations illustrated in Figure 2:

- **Drone design** (Dark blue): The shape of the drone has been shown to affect how users perceive it [19] in view of collaboration. In addition, a range of interaction modalities can be used, such as speech, gaze, or gesture [11]. These verbal and non-verbal cues are especially useful to coordinate actions between agents and improve transparency of actions.
- **Drone movement** (Light blue): Several aspects of movements matter for handover and co-working, such as the robot's velocity [14, 20], approach direction and trajectory [8, 20], lateral distance [20, 21], and flying height [21].
- **Robotic Arm** (Orange): In addition, the initial configuration of the manipulator and its retraction speed [12] need to be controlled for the handover, as well as the grasping strategy [10] (e.g., directing the object's handle towards the receiver).
- **Object** (Yellow): Finally, the object shape will not only affect the robotic arm's end effector, but also the ability to receive the object [10].

3 SCENARIOS OF USE

Based on the identified factors for handover and collocated collaboration strategies between a human and a drone (Figure 2), we designed and developed three scenarios of use in the context of construction (see photograph for each scenario in Figure 1).

- **Scenario 1: Handover of a tool from the drone to the worker**. The drone approaches the user from the side (left or right) until it reaches a position in front of or next to the user. The drone arrives from an altitude higher than the user but within reach of its arm, which is holding the needed tool. The user will be alerted of the drone coming from its side thanks to the noise generated by the propellers. The tool's handle is directed towards the user, making it easier for them to receive it. The arm is positioned either towards the user or away from them based on the physical space constraints. Once presented with the tool, the user takes it from the drone, which releases its grip and flies away.
- **Scenario 2: Co-working task for the drone and worker to hang a long object collaboratively**. The collaborative task starts with the drone and the worker holding a cable simultaneously at both ends. The drone helps sustain the weight of the cable while the worker is positioning it. The drone can also help position the cable on its end. In our implementation of the scenario, a wide panel is positioned in front of both drone and user, with two hooks on top of it, on which the cable must be placed. The drone and the user proceed together towards the board while holding the cable. The drone holds one extremity of the cable in place while the user positions the other extremity. The task ends when the cable is properly positioned.
- **Scenario 3: Handover of the tool from the worker back to the drone**. The drone approaches the worker, who maintains their position in the workspace. The approach is designed in a similar way to scenario 1. Once the drone is sufficiently close to the worker, the latter attaches the tool onto the drone's arm. The robot then pulls in the object at a comfortable retraction speed and leaves the worker.

We produced one video clip per scenario using a Wizard-of-Oz technique to ensure the safety of the person next to the drone. We conceived these scenarios for a semi- to fully autonomous co-working drone and the videos do not portray how the drone is being controlled. In addition, we envision such drone to directly communicate with the user, but this is not described in the videos to leave it to the viewer's imagination. To ensure the credibility of the videos, the worker was equipped with protective clothing, including a vest, a helmet, and gloves (see Figure 1). The videos lasted approximately 22 seconds each.

4 APPARATUS

The co-working drone used in this project is based upon the FiberTHex [13] (Figure 1), a custom-designed fixed-tilted hexa-rotor developed at LAAS-CNRS. To ensure user safety, we designed and 3D-printed protective propeller guards that we mounted beneath the motor and propellers of the drone (Figure 3). These are strategically positioned since in our scenarios the drone flies above the user. This co-working drone is equipped with a robotic arm mounted underneath it. This arm includes three rotational joints: two at the shoulder and one at the elbow. The robot is secured to the drone cage's ceiling by means of a cable. Finally, in case of emergency, a trained operator can immediately disconnect the drone's power using a dedicated safety switch.

Figure 3: Each propeller of the hexacopter has been fitted with a guard, including a net on the bottom part to increase safety (e.g., avoid collision incidents).

5 INTERVIEWS

To collect feedback on our scenarios, we conducted semi-structured interviews with potential users.

5.1 Participants

We selected three participants who each had experience related to our scenarios of use. P1 (32 y.o.) has been working as a site supervisor on construction sites for 8 years. He had seen drones before the interview but had not piloted one. P2 (57 y.o.) has been working in the field of plant protection for 38 years and has already piloted drones but does not own one. P3 (24 y.o.) has been working in the field of embedded cyber-physical systems and robotics for 3 years and has experience with construction work in his personal life. He previously owned a drone, which he used for video footage.

5.2 Method

We ran semi-structured interviews either in person or online. We first inquired about each participant's working experience. We then showed them the three video clips for the three scenarios. After each video, we asked them to describe, in their own words, what they saw. This allowed us to verify that all participants understood the scenarios. Afterward, we asked them who could benefit from such co-working drone, which tasks a drone collaborator could help with, what the advantages and disadvantages would be, and finally, we asked them to estimate the perceived usability for their own profession on a 5-point Likert-Scale.

5.3 Results

All participants correctly understood the content of the videos. Scenarios in construction work where a drone collaborator could be helpful that were mentioned by participants included: carrying buckets or small tools, pins, and supplies (P2). Professions mentioned that could benefit from a drone collaborator included electrician or plumber (P2). Yet, P1, who has experience working on construction sites, stated that a drone co-worker should not be required provided the construction is well planned (e.g., anticipating which tools are needed and taking them along when working at height). He suggested that a drone would instead be useful if it could lift more weight, such as high-pressure cleaners, parts for constructing cranes, or insulation for the roof. Moreover, he mentioned that a drone could e.g. inspect the quality of paint jobs on the ground or locate and measure deformation on a dam. Finally, he suggested that drones *"could solve problems of distance, height or access, especially in the nuclear sector"* (P1, translated to English). Similarly, P3 mentioned maintenance for the energy sector, buildings, or aircraft and large places (e.g., parks, warehouses) where the drone could search, pick up, fetch, or deliver packages.

Beyond construction work and in line with his own profession, P2 imagined a co-working drone picking crops or carrying baskets in greenhouses, similar to ground robots already used in agriculture. He also mentioned treating moss-filled roofs, which is currently done using a truck that sprays the roof. Another scenario concerned destroying hornets' or wasps' nests with a small-size drone that can go into narrow spaces, or treating infected trees (e.g., pine processionary moths), but only if the drone could manipulate the necessary tools. If the drone was equipped with a laser sensor measuring height, it could also be used to trim hedges.

The perceived usability of the drone for their own profession varied greatly across participants, from 1 (P1) since it would require training the humans, and as it is already difficult to recruit qualified workers; to 2.75 (P2), since many tasks involved moving at height; and to 4 (P3) since it *"can scale up things we can already do"*.

The main advantages that were mentioned were the diminished physical effort related to moving and walking (P2), improved efficiency since users would not need to leave their position to get tools and hence gain time and comfort (P2, P3), high precision and doing "*things perfectly if programmed correctly*" (P3). Other advantages of a drone collaborator included that it would always be available when needed (except for battery and electronic issues, P2), but when not needed, it could be stored away and not disturb the workers. P1 mentioned that using drones could reduce the need for scaffolding or access platforms.

Disadvantages included the need for training co-workers (P1), to charge batteries (P2, P3) and to do the work alone while the drone is charging (P2); the space required to store and manipulate the drone (P2); and that it "*screws up if programmed incorrectly*" since drones are not yet fully autonomous (P3).

Participants also made suggestions for further improving the system. For instance, P2 suggested equipping the drone with a computer vision system to film the space and convert it to 3D maps.

5.4 Discussion

Our interviews allowed us to identify use cases where co-working drones could be helpful, beyond our scenarios, such as plant protection or for inspection. Some of these would require increasing the drone's capabilities, such as by adding sensors or carrying heavier charges. The main advantages found were improved efficiency, precision, and comfort. It was also highlighted that current drone technologies have limitations that would need to be overcome to reach full potential, e.g., longer battery life. Beyond these limitations, already shown previously (e.g., [5]), our construction workers highlighted the difficulty of training human co-workers for collaboration with aerial robotic partners.

6 LIMITATIONS & FUTURE WORK

This project addresses a futuristic scenario. Hence, we did not have access to users with experience in co-working with drones in real-life situations. We used videos to project users in the context of co-working drones and interviews to obtain information on possible drone uses, advantages, and drawbacks. Another limitation lies in the difficulty of recruiting participants with experience working at height, and a more diverse participant group. In addition, we encountered limitations with the drone hardware, which hindered us from evaluating the three scenarios safely in in-person user studies. In general, drones developed for co-working are traditionally larger than the ones used in Human-Drone Interaction so far, and include additional flight constraints due to their given abilities (e.g., robotic arm). As such, additional research is needed to fully understand how these drones can interact safely in proximity with human users while supporting them in their tasks. One important next step will be to design and implement interaction techniques for seamless collocated interaction between worker and drone, enabling both human and robot input in case of uncertainties or fine-tuning. This will be especially important in the realization of complex tasks.

7 CONCLUSION

This paper describes the first steps towards handover and co-working considerations when collaborating with collocated drones, e.g., for construction sites. Based on the prior work, we propose considerations for human-drone collaborations and handover, which include items such as: drone design, drone movement, robotic arm design, and objects to be handed over. Using a co-working drone equipped with a robotic arm, we designed and developed videos showing three scenarios of use: handover drone to human, collaboration, and handover human to drone. An interview study with three participants with experience working at height or on construction sites allowed us to gain insights into the advantages and drawbacks of drone co-workers, as well as possible use cases in which drone collaborators could be beneficial. The interviews allowed us to identify scenarios outside of construction work for which drone co-workers could be helpful (e.g., plant protection and supervision of nuclear sites). We plan to extend the scope of our work to these scenarios. Future work will include conducting in-person user studies.

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