Elevating Communication, Collaboration, and Shared Experiences in Mobile Video through Drones

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ABSTRACT
People are increasingly using mobile video to communicate, collaborate, and share experiences while on the go. Yet this presents challenges in adequately sharing camera views with remote users. In this paper, we study the use of semi-autonomous drones for video conferencing, where an outdoor user (using a smartphone) is connected to a desktop user who can explore the environment from the drone's perspective. We describe findings from a study where pairs collaborated to complete shared navigation and search tasks. We illustrate the benefits of providing the desktop user with a view that is elevated, manipulable, and decoupled from the outdoor user. In addition, we articulate how participants overcame challenges in communicating environmental information and navigational cues, negotiated control of the view, and used the drone as a tool for sharing experiences. This provides a new way of thinking about mobile video conferencing where cameras that are decoupled from both users play an integral role in communication, collaboration, and sharing experiences.

Author Keywords
Video communication; drones; telepresence; teleoperation; collaboration; shared experiences; CSCW; HRI

ACM Classification Keywords
H.5.m. Information interfaces and presentation: Group and Organization Interfaces – *CSCW*

INTRODUCTION
We now see many situations where people use video conferencing while on the go to receive or provide support in collaborative tasks [2], to show and communicate things (e.g., asking someone what to buy in a store [14,30]), or to share experiences (e.g., taking someone on a tour [2]). We are especially interested in scenarios where a *field person*, who is outdoors, is interacting with a *desktop person*, who is at a distance from the field person. Examples of such scenarios include families sharing specific activities (e.g., seeing a kid's soccer game [12], going to the zoo [28]), giving navigational directions (e.g., a remote person guiding someone through an unfamiliar place), and searching for items together in a large space (e.g., deciding on food items from a group of restaurants [14]).

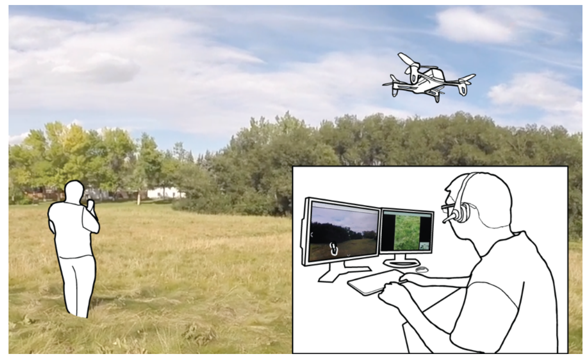

Figure 1: A mobile-video-conferencing configuration involving a drone.

Yet, in these situations, the experiences of the desktop person are fundamentally limited by the technology used by the field person, frequently a handheld smartphone camera—the camera field of view (FOV) is limited, and the desktop person has poor situation awareness [5] and very limited control of their perspective [12,14,34]. Because the desktop person's perspective is effectively controlled by the mobile participant, view changes need to be communicated explicitly and verbally, putting undue burden on the field person and easily frustrating the desktop participant [14,20].

Drones, or unmanned air vehicles (UAVs), may address some of these limitations in mobile video conferencing applications. Drones can provide the desktop person with more control over the view itself, and also offer views into environments that are otherwise difficult or impossible to achieve (e.g., bird's-eye view) from the field person's perspective. Drones are already used to capture events and activities for watching and sharing at a later time (e.g., [43])—partly because they capture action from high above with a wider FOV, providing a better sense of the overall context of the activity. Because of their relatively low cost and high versatility, we see the potential that drones have to

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support mobile video conferencing. However, we currently know little about how people would make use of them and what challenges they might experience.

In this paper we study how people use semi-autonomous drones for video conferencing: here, the field person is ‘on the go’ holding a mobile device, and video chatting with a remote desktop person, who can view the environment from the perspective of a drone in the field location (Figure 1). By observing pairs of people perform collaborative navigation and search tasks, we identify several strengths of this configuration that go beyond what is available in physical co-presence [11]. First, the desktop person can now independently participate in acts of ‘camera work’ by changing their own view of the environment with less involvement from the field person (cf. [14,20]). Second, the drone view provides a complementary perspective that is physically inaccessible to the field person—this gives each communicator the potential to have (and share) information that the other does not have. This illustrates the value of a camera that is decoupled from the remote user’s body and, in turn, suggests new ways of thinking about camera placement and access for remote users. Drones are certainly not without their problems, however. Our findings suggest that naïve implementations of drone-supported video conferencing may still prove insufficient for people’s communicative needs.

We make two contributions in this paper: (1) we present the design of a drone-video-conferencing prototype system, and (2) we present the first study of drone-supported video conferencing, outlining new interaction challenges and opportunities with regards to using the drone as a shared communicative, collaborative, and experiential resource.

BACKGROUND

We frame our research from three prior work perspectives. First, we consider the challenges presented by mobile video conferencing, where ‘on-the-go’ participants are interacting with remote participants via a video connection. Next, we outline robotic telepresence literature, which helps inform our understanding of people’s experiences of embodiment when it is mediated through a robotic entity in a remote environment. Finally, we discuss some of the current efforts on collocated interaction with drones.

Mobile Video Conferencing

With the rapid evolution and adoption of mobile devices and cellular networks, mobile video conferencing is becoming increasingly commonplace. People now use mobile video conferencing to communicate, collaborate, and share experiences with distant others.

Communication. People video chat often to show things to someone [30]. Such activities include showing things in the home or workplace [30], showing important life events (e.g., a wedding [26], a kid’s first steps [2]), taking someone on a tour [44], and showing items at a store or restaurant [14,20]. In addition, the person not in the activity space (the space containing the items/landmarks of interest) may want to communicate certain things (intents, details, object references, etc.) to the person in the activity space—however, with conventional mobile video conferencing tools, this can generally only be done verbally, and adds overhead and awkwardness to the interaction [14]. Researchers have studied various ways of providing the remote person with a means of referencing things and conveying intention—for example, through on-screen annotations [7–10,21] and tele-pointing [16].

Collaboration. A problem related to that of being able to reference is that if the remote person does not have a sufficient view into the activity space (which is often the case, especially for conventional tools that provide a single view with limited FOV), they will not get a full understanding of the space and the status of the activity; and thus they may lose out on opportunities to contribute to the activity at hand [14]. Researchers have attempted to address this by, for example, providing the remote user with a higher FOV view into the activity space [17,18], by providing the local user with a shoulder-worn mechanical camera that can be operated by the remote user [19,22,23], or by providing the remote user with a large composite view into the activity space constructed by stitching sequences of images of the space taken over time [16].

Sharing Experiences. In addition to communicating and collaborating, people also use video conferencing for sharing experiences [2,15]. Some of the challenges in using video conferencing for communication and collaboration outlined above also apply to its use in sharing experiences. For example, in many ‘shared-experience-type’ scenarios (e.g., showing life events), a poor view of the action renders the connection unviewable and frustrating, resulting in a poor experience for the remote person. In addition, people observing an activity remotely might want to control their view into the environment [12], interact with the people who are part of the activity [12,26], or perhaps even participate in the activity on their own in some way [12]. Conventional mobile video conferencing tools make this difficult; and consequently, remote users often disengage in the shared activity [14]. Tools such as Periscope [45] (while not necessarily video conferencing) provide viewers with a basic means of ‘participating’ in an activity and interacting with the people involved by sending text-based messages and ‘hearts’ to the user operating the camera. While technology and research have come a long way in providing improved ways to remotely observe an on-the-go activity, there is still much work that can be done in terms of allowing remote users to more meaningfully participate in these types of activities.

Explorations in Telepresence and Teleoperation

Researchers in telepresence and teleoperation have long tackled a similar problem space, where the principal concern is to allow a remote participant to engage effectively in the local space. Some explorations have

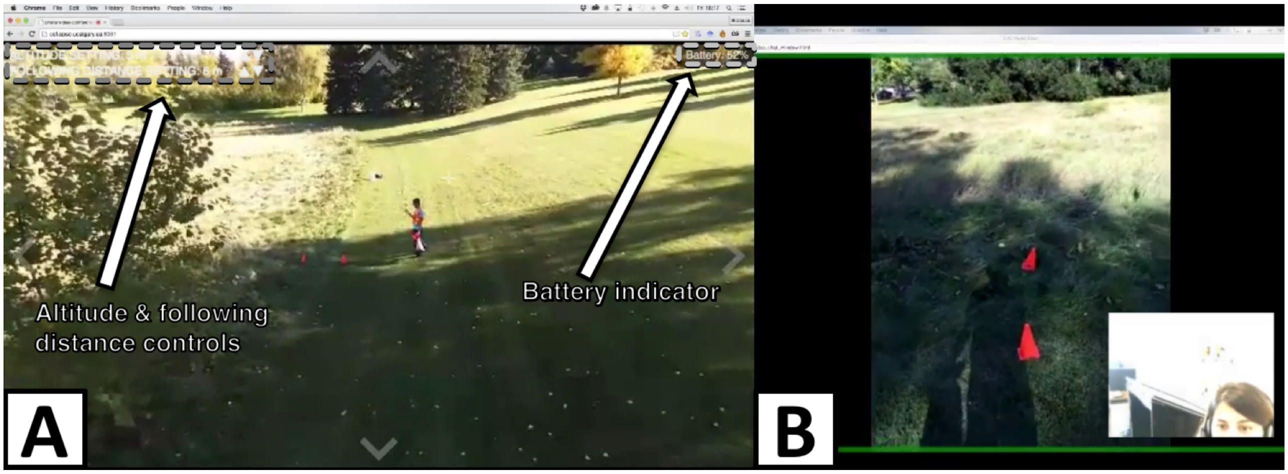

Figure 2: The desktop interface—the left monitor (A) contains the drone camera view and a number of indicators and controls, while the right monitor (B) contains the Skype-like video-chat interface.

focused on different ways of embodying the remote participant, and the social consequences of these styles of embodiment (e.g., [32,33]). Other research has explored the use of mobile remote proxy (MRP) telepresence robots in office environments (e.g., [24,42]), homes (e.g., [1,41]), and other settings (e.g., [4,29]).

Teleoperation of robots introduces numerous challenges with regards to awareness in a remote environment. For one, an operator's awareness of the space is solely reliant on the information being fed to him/her by the robot, which is often restricted to video/audio streams and other sensory data. Restricting perception to a single video stream reduces the operator's awareness of the space solely to the perspective of the camera providing that stream. Providing multiple video streams from varying perspectives can potentially help improve this issue, but it also introduces a number of additional challenges. For one, integrating information from one view to another can be difficult (e.g., [31,39,40])—this introduces challenges such as figuring out where the multiple view perspectives are in relation to one another, and figuring out where objects of focus are in relation to the multiple view perspectives. Thomas and Wickens [39] found that operators receiving information from multiple view perspectives often focus their attention strictly on one view, even when other views are providing useful information. This is because putting mental focus on one view, rather than managing and switching between multiple view, is less cognitively demanding, especially when there is a task at hand that requires focus. Researchers and designers have explored various means of presenting multiple views to operators while reducing the cognitive effort of managing such views, including through auditory alerts [31], smooth transitioning between views [31], and sensory "egospheres" [13].

In addition to reduced awareness of the space, another challenge which was anticipated by Paulos and Canny [33] and frequently reported in the literature (e.g., [24,35,42]) is that piloting MRPs is cognitively demanding: in addition to participating in the activities in the remote space, the MRP still needs to be piloted. In some cases, the efforts are so taxing that MRPs are sometimes left in awkward locations [24] rather than being properly piloted "home" (i.e., to their charging stations). Additionally, referencing objects in collaborative physical tasks can be a challenge, because the MRP's mobility impairs people's ability establish a coherent spatial reference [25,29,35].

Collocated Interaction with Drones

Drone interaction has long been, and continues to be, of interest in the HRI community. Interesting challenges of interacting with collocated drones emerge from people's tendency to perceive and infer affect and intent from the flight paths of collocated drones [36,37]. Mueller and Muirhead's [27] exploration of drones as running companions provides a practical example: runners were frequently uncertain of how to control the collocated drone, and/or whether the drone understood what they were doing as runners. As a result, researchers have developed simple ways of expressing and communicating drone intent expression. For example, Szafir et al. has used an LED ring under the drone [38], and flight primitives based on natural motion principles to indicate movement intent [37].

SYSTEM DESIGN

We focus on video conferencing scenarios between two people, where one person is moving around a large outdoor environment (the field person, or *FP*) and the other person is sitting at a desktop workstation (the desktop person, or *DP*). Such scenarios could involve activities such as giving a tour (e.g., of a nature area or tourist attraction), searching (e.g., search and rescue), event setup (e.g., for concerts or festivals), and site inspection (e.g., of construction sites or outdoor facilities). We designed a mobile video conferencing system (Figure 1) that connects the FP with the DP, and where the FP is followed by a drone. The drone autonomously follows the FP, showing the DP a third-person bird's-eye view of the FP and his/her surrounding environment. The purpose of this view is to provide an overview of the FP's environment to the DP and to show

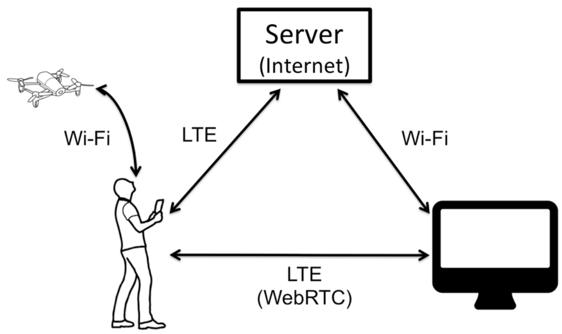

Figure 3: Block diagram of the system design.

the FP in context of his or her larger environment. While the DP has no direct control of the drone's movements (since the drone always autonomously follows the FP), the DP can control the (virtual) pan and tilt of the camera attached to the drone (within a ~180° range for both pan and tilt), and adjust the altitude above the ground and the distance from the FP. The FP has a mobile phone that he/she can use to show detail views of the environment if necessary.

Interface. Figure 2 illustrates the interface that the DP uses: it provides two separate views—the view from the phone held by the FP, which resembles a traditional video-chat interface (e.g., Skype), and a view from the drone. The DP can manipulate the virtual pan and tilt of the drone camera via use of the keyboard arrow keys or via clicking arrow buttons on the drone view. This view also has indicators and buttons allowing the DP to view and adjust the altitude and following distance parameters that the drone is trying to maintain. Finally, it provides a simple green outline indicator to show if the FP's phone interface is displaying the drone view or the video-chat view.

The FP's phone has a very simple interface, showing either the drone or the regular video-chat view, where the FP can toggle between each. The FP can also toggle between the front- and back-camera views from their phone. This allows the FP to have a conversation as 'talking heads', or to show the DP something in the local space. A two-way audio link is maintained regardless of which view is being used.

System Components. Figure 3 illustrates the four components of the system: a drone, a smartphone, a server and desktop machine. The Parrot Bebop drone has a virtual pan-tilt camera providing an approximately 180-degree FOV (e.g., a fisheye lens), and is controlled by a custom iOS smartphone app connected via an internal Wi-Fi. The iOS app runs on the FP's smartphone (iPhone 6+), where the smartphone acts as the gateway (via LTE) to the other devices. A Node.js server relays information and commands between the smartphone and desktop, and helps establish a WebRTC video/audio call between the phone and desktop web application. The desktop web application allows the DP to adjust parameters (following distance and altitude) and control the pan and tilt of the drone camera.

Drone Control. Because one of the big challenges reported in prior robotics telepresence and teleoperation research is that piloting tends to be challenging (e.g., [32]), we reduce the load on the DP. In our design, the drone follows the FP autonomously, and the DP's controls are limited to adjusting the virtual pan and tilt of the drone camera, setting the altitude at which the drone flies, and setting the distance at which the drone follows the FP. While the DP can look around, the view is limited to a particular viewing cone, and the drone's position is essentially controlled by an imaginary leash tethered to the FP. A major trade-off of giving more direct control to the DP is that, while it gives the DP more flexibility, it also increases the cognitive load of piloting, which would have to be done alongside completing the task with the FP. That said, it could be beneficial to give the DP greater control of the drone for certain types of activities—particularly those that require free movement within a space without necessarily being tethered to any one person (e.g., search and rescue). We leave explorations of other control strategies for future work.

Follow Algorithm. The drone uses a simple control loop running at 40 Hz to follow the FP, where both the drone and FP are tracked via GPS (the FP via the smartphone's GPS). At each step, the drone checks three things: (i) its bearing (i.e., pointing direction) to ensure the FP is within an appropriate range (20 degrees), (ii) the distance from the FP (to ensure the FP is within range), and (iii) the altitude (to ensure wind has not blown it off course). Once this check is complete, the drone makes micro-movements to correct for each of these factors (i.e., turn if necessary, move toward the FP if necessary, and fly up/down as necessary). This happens without explicit action on the part of the DP.

Safety. Not shown in Figure 3: the investigator is connected to the entire system with override controls to the drone—for example, to safely land the drone. In pilot studies, we found it necessary to include an emergency safe landing feature, as the drone would sometimes wander too close to trees, the FP, or the bounds of the activity space. Much of this is attributable to GPS or compass inaccuracies.

OBSERVATIONAL STUDY

We designed an observational study to understand how people would make use of our system to communicate and work on collaborative activities. Our study was framed around three central questions:

- How does the drone view benefit or hinder the DP in communication and collaboration?
- How do FPs perceive and interact with the drone?
- How do pairs utilize the drone as a shared resource for communication and collaboration?

Participants

We recruited eight pairs of participants through poster ads placed around our university campus and through online ads. One participant's (G3-FP) demographic data was lost. There was initially a ninth pair, but we dropped their data from the full study due unacceptable network latencies (i.e., greater than 10 seconds). The remaining 15 participants (eight female, seven male) ranged in age from 19 to 32 years old, with a mean age of 23.7 years. All but one pair were current university students, and the remaining pair had university education. All participants knew their partner prior to the study, with a wide range of existing relationships, including: friends (two groups), colleagues (two groups), spouses/dating (two groups), roommates (one group), and parent/daughter (one group). All participants had prior experience with video conferencing, with eight responding that they used it "very often", five saying they used it "sometimes", two using it "rarely", and zero using it "never". Eight participants reported previous experience with video chatting while on the move or with a mobile device (e.g., phone, tablet). We recruited the participants as pairs to ensure they had pre-established rapport, and asked that one member of the pair be comfortable with walking around outdoors in a large field containing tall grass.

Method

Participants completed a warm-up task and two study tasks together. The DP worked from a desktop in an office environment, and controlled the view of the drone. We asked the FP to wear a bright retro-reflective vest so that they were more easily visible from the drone camera view. The overall duration of the study ranged from 60 to 90 minutes.

Arrival, Locations, and Warm-Up Task

We asked participants in each pair to arrive at two different locations: one at our research lab, and the other at a nearby park. The park contained a field measuring roughly 70m x 140m that had a large, circular section of tall grass surrounded by trimmed grass. The field was also surrounded by irregular patches of bushes and trees. Upon arrival, each participant began the consent process, was briefed on the overall purpose of the study, and was introduced to their respective software interface. The participants then completed a warm-up task, giving them the opportunity to familiarize themselves with the system. For the warm-up activity, we asked participants to talk to each other while the FP walked around the park with the drone following him/her around. The DP practiced adjusting the controls and moving the camera on the desktop interface. The warm-up activity continued until either the pair said they were ready to continue or the drone battery depleted.

Study Tasks

Participants then completed each study task in turn. After each task, each participant provided a quick, independent verbal reaction to capture his/her immediate thoughts on the experience. Between each task, participants waited briefly (~5 minutes) so that the study investigator could switch batteries and restart the drone. Upon completing the second task, both participants completed a post-study questionnaire and demographic survey. Sample questionnaire questions included: "To what extent did you enjoy video conferencing with your partner?" and "How immersed did you feel in the activity?" Finally, we interviewed participants about their experiences as a pair through the video chat in order to understand their experiences as a group. Sample interview questions included: "What kinds of problems did you encounter as a group?" and "How do you think the experience would have compared to being physically together?"

We were interested in recreating scenarios where there was plenty of back-and-forth interaction between the FP and DP, in order to understand the role of our system in supporting communication and collaboration towards a shared goal. While this goes beyond activities that mostly involve passive observation from the remote user (e.g., watching a soccer game [12], viewing a tour [44]), these activities could still involve some active control and participation from remote users—indeed, one of the main goals of our design is to support and encourage active participation and engagement from the remote user. We designed the tasks based on anticipated styles of use: searching for things together (e.g., [34]), and exploring environments together (e.g., [14]). In doing so, we aimed to include subtasks that comprise these broader activities, including: navigation style tasks (where one participant directs the other to a location), examining and exploring physical objects, and differential knowledge/knowledge sharing tasks. In designing these tasks, we were not so much interested in whether participants completed the tasks quickly; but rather in the ways in which they approached the tasks and communicated with one another.

Study Task 1: Setting up the field for an event. The DP is given a set of instructions for how the field ought to be set up with physical props (three pylons and two bags of coloured balls). These instructions include an overhead map of the field with written directions about how and where the props should be placed. This task was designed to primarily be a navigation task, where the DP directs the FP to the correct location for each prop. The FP's role is mainly to move about the space, provide an 'on the ground' perspective from his/her mobile phone, and place objects according to DP's directions.

Study Task 2: Scan and search. In this task, the DP and FP navigate through several locations in the field together. Each location (20 in total) is marked by a hula-hoop, where each hula-hoop is of one of five colours (red, pink, yellow, green, or purple), and has one of four symbols (|, +, ^, or =) through the centre of the hoop. The DP's instructions include the sequence of hula-hoop symbols to navigate through, but not the hoop's colour. Meanwhile, the FP is given the colour of the first hula-hoop and each visited hoop provides the colour of the next to visit, but not the symbol. The task is to pass through as many locations as possible in the correct sequence within the drone's battery-

Figure 4: Hula-hoop colours are often visible from the FP's perspective (right), but not from the drone view (left).

life timeframe. As illustrated in Figure 4, we designed this task in such a way that the colours of nearby hoops were only visible from a ground perspective, while the symbols of the hoops in the general vicinity were visible from the sky. This design resulted in the FP and DP having different pieces of information seen from different perspectives of the space: the FP knowing the colours of the hoops from the ground perspective, and the DP knowing the symbols of the hoops from the sky perspective. This task is a dual searching task where both the DP and FP need to inspect the environment (at different scales), navigate (where the DP will direct the FP, and the FP informs the DP where he/she is), and share/exchange knowledge with each other as they problem solve together.

Data Collection and Analysis

We collected position and bearing data of both the drone and the smartphone on a 0.5-Hz interval. We also collected and logged information about FPs' interactions with the interface (e.g., when does the FP have the drone view open, when is the FP using the front/back camera, etc.) We captured the video from the drone and smartphone, and the conversation across the video-conferencing link. We augmented this with video captured from a head-mounted camera worn by an investigator that we used to follow the FP around. Finally, collected field notes from direct observations of the FP and the DP.

We conducted a thematic analysis based on field notes and interview data. Using this an initial set of themes, we iteratively reviewed and selectively transcribed the collected video data. This process resulted in an understanding of the general flow of participants' actions, as well as a set of critical incidents that illustrate or highlight challenges that participants experienced.

FINDINGS

In total, our analysis covers the experiences of eight pairs. For three pairs, the drone crashed into trees or experienced a glitch in the altitude control; but these all occurred late during the task at hand, so we kept the data for analysis. Pairs generally completed the first task without too much difficulty, though all pairs struggled to complete the second task in the allotted time.

We outline three main themes that emerged from our observations of participants' experiences: the DP's experiences of the drone's perspective, the FP's experiences being collocated with the drone, and utilization of the drone as a shared resource. Throughout our results, we refer to audio transcripts and participant quotes where we label them with *G#* for group number followed by DP or FP, depending on the participant's role.

Experiences with the Drone as a DP

Participants, particularly DPs who viewed the scene primarily through the drone view, enjoyed the experience. Most salient of these responses was from G7:

> **[G7]** DP: This is super cool... It was cool that I could almost be in the park with [FP]. I feel like I've been outside this morning.

Bird's-Eye View. While participants generally expressed excitement over the novelty of the bird's eye view, these positive feelings were also reflected in comments about the utility of the view in terms of the task:

> **[G7]** FP: It was helpful to have the bird's eye view. [DP] could see things I couldn't see, and I could see things she couldn't see.

> **[G2]** DP: Better [using the drone] to see the world view and help him see what's available.

Dual View. Pairs used the smartphone cameras in a variety of ways where both the back camera (first-person view) and front camera (third-person view of the user's face) were valued. Based on prior work, we generally expected FPs to use the back camera to provide DPs with detailed views and information (e.g., [14]) that could not be seen from the drone. Yet, FPs used these views in a number of unusual ways, for example: using the back camera to show scenery to establish common ground, showing a view of themselves, and other times (as can be seen Figure 5, where G5-FP covers the camera with his finger), they would forget the camera was there altogether. The use of the front camera to show the FP's face provided enjoyment to the DPs (similar to [12,42]) allowing the DPs to see both the task environment and the FP's reactions to the task.

Altitude-vs.-Resolution Tension. The altitude and following distance of the drone were the only sources of flight control for DPs. This brought with it an interesting tension—on the one hand, DPs wanted to see more of the field to gain visual context; on the other hand, being very high meant that DP had difficulty seeing visual details in

Figure 5: G5-FP points with the intention of his gesture being visible from the drone view (left). At the same time, he ignores what is visible in the phone view (right).

the scene. All DPs mentioned having difficulties seeing certain details (such as the colours of the hula-hoops, as was intended by the design of Task 2) in the drone view.

Providing Navigational and Directional Cues. While our design provides a means for the DP to look around, DPs had a difficult time communicating where the FP should go. As the DP was tasked with helping the FP to navigate the environment in both tasks, we observed breakdowns in these communicative acts across all pairs. We consider two distinct challenges faced by our participants: first, that DPs were not always aware of where the FP was located relative to the drone, and second, that the DP and FP had completely different frames of reference.

Providing directional cues for someone necessitates an understanding of their location and perspective on the world. Without this, it was difficult for DPs to provide FPs with directions. In spite of the drone's "follow" algorithm, the FP would sometimes move out of view of the drone. For example, in one instance (G5), the FP was out of view because of a tree that blocked the drone's view. We expect that these types of occurrences would happen more frequently in general—for example, urban environments contain more tall obstacles (trees, buildings, etc.).

Assuming the FP was in view, the next challenge was that the DP and FP had completely different frames of reference: the FP had an egocentric view from the ground, while the DP had a view from the air without necessarily being oriented in the same direction as the FP. While DPs understood this difference, it was sometimes difficult for them to remember it when deeply focused on completing a task (similar to [31,39,40]). For instance, in G1, the DP occasionally told the FP to move straight up or down, but this was in reference to the screen space of the drone's view rather than asking the FP to move forward or backwards (or up into the air, for that matter). There were some common workarounds to this. For example, one workaround was for the DP to try to provide directions in the FP's frame of reference, by saying things like "to *your* right" (G5) and "at 10 o'clock from you" (G7). One group (G8) also made references in relation to the drone's perspective—e.g., by saying "walk toward the drone." Another workaround was for participants to refer to landmarks and objects in the park—for example, the "scraggily tree" (G7) and the "flat part" of the grass (G5).

Limited Drone Control. DPs were motivated to "look around" from the drone for two reasons: first, DPs looked around to explore the space, and second, DPs looked around to try to locate the FP when the FP was no longer in view (as discussed above). The limited drone control proved frustrating to our participants. While participants understood the limited view of the drone, we nevertheless observed DPs tapping on the keyboard furiously trying to see more of the scene. When trying to provide navigational cues, not being able to see the FP was extremely frustrating for DPs—two of whom (G3 and G5) resorted to shouting, "where are you,"—especially when they knew the FP was immediately under the drone itself.

Experiences with the Drone as an FP

The drone itself was noticeably noisy. While most FPs reported feeling comfortable around the drone, some FPs reported feeling somewhat disturbed by the noise:

> **[G5]** FP: When you hear it getting louder, you're like, 'Is it coming in for the kill?' But once you look back and realize it's not that close, it [feels] okay. It kept its distance.

Other FPs felt a certain sense of responsibility for the drone, knowing that their movements on the ground were what moved the drone around. In this sense, because the drone's position was being controlled by the FP, the FP had an increased stake in staying focused on the task and his/her partner's needs as opposed to losing interest in the task or moving to more loosely coupled forms of collaboration.

> **[G4]** FP: I felt a bit responsible for it, in terms of making sure that it flew properly. That is, I was worried it might fly where it shouldn't.

Some DPs even noticed this sense of concern in their partner. Others expressed concerns over the safety of the drone and would suggest certain movements to their partners to minimize potential damage to the drone.

> **[G4]** DP: It's going for the tree! Can you just walk [quickly] away from the tree?

In one case, the DP makes explicit mention of this concern in a comment to the FP:

> **[G7]** DP: I think the one question we should ask [to the experimenter] is how to safely land the drone. *[DP lowers the altitude of the drone to the initial setting, thinking that this will keep things safe.]*

FPs also became concerned when the drone flew too far away from them—this likely stems from the feeling that the FP lost the drone (and perhaps by extension, the DP) or that the drone is wandering off.

In our study, the investigator in the field had the ability to override the drone in case something went wrong. In a real-world scenario, this type of intervention likely would not exist—or if it did, it would likely not be in the hands of a third person. In our study, even though the investigator was fully responsible for the drone (and participants were aware of this), FPs still felt some sense of responsibility and concern for the drone. This sense of responsibility would likely increase in a real-world situation where the drone (semi-) autonomously follows the FP without any direct intervention from a third person.

Because we designed the drone for the DP, we had neglected to fully consider the experience of the drone from the FP's perspective, or even of it as a separate entity. We see now that the FPs are very much aware of the drone's presence, even leery of its presence, and that both FPs and DPs were concerned about the flight path of the drone.

The Drone as a Shared Resource

Rather than strictly using the drone as the DP's view into the activity space, pairs also utilized the drone as a shared resource. This is a reversal of the roles that has been reported in the literature, where the field person needs to work at the behest of the desktop person (e.g., [14,20]).

Position, View, and Attention. Because the drone movement was autonomous (and out of the active control of either participant), participants devised workarounds to "control" the drone. In this vignette (during the warm-up task), the FP explains out loud what he is doing to the DP and continuously asks the DP if she has a good view:

> **[G3]** FP: Can you see me? […] I [am making] slow movements, so that the drone has to follow me. […] It's very close to me now, so I'm just going a little away from the drone. […] Are you able to see the distance between me and the drone which follows me? […] Is it okay now?

It was in the interests of both the DP and the FP to make sure that the drone was providing a good camera shot. Several FPs regularly checked during the tasks to make sure that their partners had a good view:

> **[G1]** FP (while looking at the drone): Do you see [the pylons]?

> **[G3]** FP: I'm near the first pylon. Are you able to monitor?

> **[G4]** FP: Do you see the drone view?
> DP: Yeah.
> FP: Okay, you should be able to see [the pylon] from the drone view.

FPs also moved around the environment to guide the drone's position and orientation:

> **[G8]** FP: I'm behind the drone. *[Drone begins rotating.]* So now the drone rotates, and you can see me here. *[FP waves to the drone while walking forward.]*

FPs would also guide the DP's actions by suggesting that the DP adjust the drone's altitude, following distance, or camera position. While doing so, FPs would also often talk about what is (and what is not) visible in the video frame:

> **[G4]** *[The FP watches the drone view as the DP adjusts the pan/tilt of the drone camera to find the FP. A few seconds later, the FP is in the drone video frame.]*
> FP: That's me. *[Referring to himself in the video frame]*

> **[G8]** FP: Can you move the drone up to see more?

FPs also commonly performed other physical actions (e.g., waving, gesturing, and pointing, as seen in Figure 5) in front of the drone camera, sometimes while watching the drone video feed, to draw attention to themselves or to other objects in the video frame. This act requires the DP to orient the drone camera properly to see both the FP and the target, so much so that in some cases, the FP would move to actively ensure that the DP had a good view of him. The following vignette illustrates how FPs were cognizant of the drone's view:

> **[G8]** FP: I think if you go lower you can have a better view of me… Go lower if you can.
> […]
> FP: I think the drone might see me now. Can you turn it to the right? *[DP turns drone camera.]* A little bit down. I should be visible. Yeah, can you see me? I'm in the bottom left.

In some instances, DPs explicitly requested FPs to move around the environment to guide the drone's position and orientation and provide better camera shots:

> **[G4]** DP: Can you walk the opposite way… so [the drone] turns around?

> **[G7]** DP: Since the drone faces you, do a little bit of walking around in a circle, so I can figure out where you are on the map that I have.

> **[G7]** DP: I don't see pluses in my view... if you turn around [I can look].

FPs Making Use of the Drone's View. The setup of the system and the tasks were designed so that the DP would watch the drone-camera view and guide the FP based on that view. Even though we designed the setup with this in mind, we also gave the FP the ability to view the drone-camera view.. Although there were some instances when the FP made use of the drone view to decide what actions to take next, in general FPs only had the drone-camera view open on the phone interface 17% of the time. FPs mainly did this at the beginning of the session to see themselves, but rarely used this view for orientation. One reason participants gave for not using the view was that, because studies were run on sunny days, the glare from the sun made it difficult to see the screen itself. The resolution of the phone's screen and the amount of small details in the drone view (due to it being up in the air capturing objects from afar) also meant that it was hard to see very much from the drone view on the phone screen.

Sharing Experiences through the Drone's View. The drone and its camera view were also utilized as a means of 'sharing experiences.' This was seen a lot particularly with Group 7—here, the FP and DP would often both look at the drone view together in order to take in the scenery and experience the environment from the same perspective. For example (during the warm-up task):

> FP: Let's see what the drone sees. *[Switches to drone view.]* Oh, that's so cool! […] Oh, this is so cool!
> *[DP adjusts the camera and altitude to keep FP in frame.]*
> DP: Can you see yourself?
> FP: Yeah!
> DP: On the bottom right.
> FP: I'm so little, it looks like I'm in a movie!
> *[DP moves the camera around to view the scenery while FP watches. They both converse about the scenery.]*

DISCUSSION

The goal of our research was to explore one possible solution for addressing a fundamental problem in conventional mobile-video-conferencing systems: that the desktop person does not have direct control over his/her view into the activity space. By using a drone, our design provides the desktop person with the ability to explore the remote environment (to a limited extent) from an elevated perspective. While our study participants thoroughly enjoyed the experience, our analysis reveals both opportunities and challenges that can inform future designs.

Challenges of Multiple Frames of Reference

A decoupled camera essentially guarantees that the FP and DP will have different frames of reference into the environment, and this introduces a number of challenges as was seen in our study and in related work (e.g., [31,39,40]). Designers should take into account these challenges while designing video-conferencing systems with decoupled cameras. Within the context of on-the-go video conferencing, the challenges include: (1) finding the FP's position and orientation in relation to the environment, and (2) translating navigational instructions from the DP's frame of reference to the FP's frame of reference.

There are a number potential technology solutions for establishing the FP's position and orientation within the view and activity space—for example, placing a marker on the video feed showing where the FP is, 'snapping' the view to the FP, displaying a map on the screen showing the positions and orientations of the FP and drone within the space, and showing the compass bearing of the camera view within the video feed.

In our study, participants made numerous references to established landmarks, such as a box placed in the field, pylons placed down by the participants, and specific trees within the park. While it often took some time for the FP and DP to establish and agree upon these landmarks, they proved to be useful for the purpose of navigation. Future technology designs could help support this type of landmark establishment—for example, by giving communicators the ability to place virtual stabilized markers within the scene (e.g., on a map of the space or within one of the video views), which could then be viewed by both communicators through (for example) augmented reality. This approach is very similar to one taken by designs for tools that support remote assistance on physical tasks (e.g., [6,8,9])—we expand the concept to larger activity spaces.

Drone Control

If the drone's positional movement is controlled algorithmically (as it was in our study), the viewing angle should be decoupled from the movement. In other words, adjustments in the drone-camera's viewing angle should not be dependent on the drone's positional movement. This decoupling could be accomplished by, for example, forcing the drone to continue to point in the direction it was pointing previously, even if it repositions itself (e.g., if the drone is initially facing away from the FP while the FP walks away from it, it follows the FP while still facing away from him/her by propelling itself backwards). In our study, the drone provided a view that was coupled with its movements—if the drone turned 180 degrees, the camera moved 180 degrees with it as well. This was disruptive to DPs as this occasionally caused drastic viewing-angle changes to occur.

Our design highlights the fundamental dilemma of providing the desktop person with additional controls: while it adds more flexibility and power, it also adds considerable complexity. In its current state, participants seemed overwhelmed with the task of visually searching the field despite not having to explicitly pilot the drone. Yet, there were times where the DPs' ability to explore the environment was impaired by the limited controls (both in terms of movement and viewing). This is evidenced by how DPs asked the FPs to move in particular ways to indirectly control the drone's position or view. Much like commercial airplanes, we suggest that drone piloting in these scenarios be modal—allowing the DP to either pilot the drone directly or enter a semi-autonomous mode where the drone follows the FP.

The Drone-Camera View as a Shared Resource

Cameras that are decoupled from the FP may easily become valuable shared resources for use by both collaborators. While our expectation was that the drone would simply be the DP's view into the environment (i.e., the DP's to use), we were surprised by how some FPs actively attempted to control the DP's view with the drone. In some cases, it was to help show the DP something, but in other cases, it was clear that the FP intended to use the view from the drone for him/herself. This raises several questions: should the drone view belong to the DP, the FP, or both; and, to what extent? How should collaborators negotiate the view? Conceivably, in scenarios where the FP is using the video chat to show the DP something in the FP's environment (e.g., a landmark), the FP may want more control over the drone (e.g., to show the DP around). Past research on mobile video conferencing has yet to show the value of such view decoupling since nearly all explorations have focused on cameras held or worn by the person in the activity space. In this work, we investigated what FPs and DPs do when they each share control of the same decoupled camera. As future work, it would be interesting to investigate (for example) what FPs and DPs would do if they were each given their own decoupled camera to control.

Elevated Roles for the DP

While the drone view has proven to be useful as a utilitarian tool for collaborating on the activity at hand, it has also been proven to be useful as a social tool for sharing experiences. Group 7, in particular, demonstrated this. Here, the DP did what she could to operate the drone camera to provide differing shots of the park and of her partner in the field. While doing so, she conversed with her partner casually while the two took in the shared view of the environment. This demonstrates a social role that DPs participating in activities like this could play—the role of the cinematographer. It is quite common at social gatherings for there to be one or a small handful of people with cameras taking photos and videos of the activity going on and sharing them with the rest of the group later on. It is not that difficult to imagine in the future a similar thing happening through video conferencing—for example: two people communicating remotely through a system like this, with one person out ‘in the world’ engaged in some recreational activity (e.g., hiking, cycling, kayaking), and the other person at a desk communicating socially with the field person and acting as the ‘camera person’, exploring the scene, taking shots of the activity at hand, and sharing those shots with the person in the field.

In addition to leisurely activities, participants mentioned that a drone-based system like this could easily support the DP in playing roles in collaborative work-related activities where having an elevated view may be beneficial. For example, a DP could play the role of a site overseer (e.g., for building construction or event setup) who watches over a job site from an elevated perspective and guides/instructs workers on where to go based on the information that he/she receives from his/her point of view. In addition, search and inspection tasks (e.g., search and rescue, disaster-scene inspection, etc.) could benefit from having one or more collaborators searching from different scales. While drones can be used for these purposes by collocated operators, they can also create potential opportunities for workers to play these types of meaningful collaborative roles without having to be physically in the space.

Being Collocated with the Drone

Balancing the size of the drone and its proximity to the FP are serious considerations to ensure the comfort of the FP. FPs were generally more concerned about the drone and its safety than for their own safety. This closely matches what has been seen in previous work investigating people’s interactions with drones [3]. As Mueller and Muirhead [27] point out: the larger the drone is, the more attention it draws. If the drone is too large, it causes a distraction. On the other hand, if it is too small, it becomes less noticeable. Similarly, if the drone flies too close to the FP, it becomes a distraction (and in addition, a safety concern). On the other hand, if it flies too far from the FP, then the FP becomes concerned about whether or not he/she has lost the drone (and by extension, the DP).

Awareness of safety warnings and protocols is also important. The system should communicate important safety messages, such as when the drone is taking off and landing, when its battery is running low, when it is too close to obstacles, and when it is malfunctioning. These are things that participants were evidently concerned about.

Extensions, Limitations, and Future Work

While the drone’s view provides a unique and useful view into the scene, current technologies limit the quality of the video feed. Current bandwidth limitations, along with the quality of the on-board camera (and limited zooming capabilities) mean that the quality is necessarily impaired. Many participants were surprised by the limited resolution and frame rate.

We also recognize that our tasks do not explore all possible situations and challenges that one might experience when using a drone for mobile video conferencing. For example, based on these tasks, we are unable to comment on DP fatigue from long-term navigation of the drone, or whether the novelty of video conferencing with a drone wears off for either participant. Beyond this, due to statutory limitations, we are limited in our ability to explore scenarios where the FP may be in heavily populated areas, or interacting with others. Finally, improvements to drone technologies in time will allow them to operate under less than ideal weather conditions (rain, high wind, etc.).

An easy recommendation for future work would be to further investigate the balance of control of the drone and its camera view between the FP and DP. For example, different strategies for control can be investigated: giving the DP complete control of the drone, allowing the DP to control the drone within an imaginary bubble around the FP or the activity space, giving the FP direct control of the drone, toggling complete control between the FP and DP, etc. Changing the control strategy would also likely change numerous other things, and thus would raise several questions—for example: would FPs feel as concerned or responsible for the drone if they have less control of it? Would DPs get a better understanding of the space and of the relationships between the drone’s and the FP’s frames of reference if he/she has more control of the drone?

CONCLUSION

Many outdoor activities can be made more enjoyable when we share them with others. In addition, some outdoor activities such as field setup, searching, and navigation may require collaboration with other people—some of whom might not be physically present. While conventional mobile-video-conferencing technologies allow us to communicate, collaborate, and share experiences with others while on the go to some extent, mobile users have to perform a large amount of camera work, which may not provide good views for the remote person. The design presented in this paper provides the remote user with the ability to explore the environment from the perspective of a drone. Our study demonstrated that while the experience still has far to go, drones provide remote users with a perspective that is enjoyable and useful. This, in turn, suggests new opportunities for mobile video conferencing where cameras can be decoupled from participants in the activity space to alleviate challenging camera work and give more freedom to the remote participant.

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