An Exploratory Study of the Use of Drones for Assisting Firefighters During Emergency Situations

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ABSTRACT

In the near future, emergency services within Canada will be supporting new technologies for 9-1-1 call centres and firefighters to learn about an emergency situation. One such technology is drones. To understand the benefits and challenges of using drones within emergency response, we conducted a study with citizens who have called 9-1-1 and firefighters who respond to a range of everyday emergencies. Our results show that drones have numerous benefits to both firefighters and 9-1-1 callers which include context awareness and social support for callers who receive feelings of assurance that help is on the way. Privacy was largely not an issue, though safety issues arose especially for complex uses of drones such as indoor flying. Our results point to opportunities for designing drone systems that help people to develop a sense of trust with emergency response drones, and mitigate privacy and safety concerns with more complex drone systems.

CCS CONCEPTS

Group and Organization Interfaces → Computer Supported Cooperative Work

KEYWORDS

Emergency calling; firefighters; drone; surveillance

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1 INTRODUCTION

Since the late 1960s, emergency services within Canada and the United States have been using audio phones calls to the number 9-1-1 for citizens to share details about an emergency and receive help from first responders (e.g., fire, ambulance, police) [44]. In the next few years, Canada will move towards Next Generation 9-1-1 where callers will increasingly use new technologies to communicate with 9-1-1 call centres [49,51]. This will include technologies such as video calling and text messaging. Yet the challenge is that these technologies will still likely leave emergency call takers and dispatchers with an incomplete understanding of an emergency situation and more information will still be valuable for first responders to know about [27,35].

Given this, our work explores the use of additional technology in the form of *drones* to provide first responders with information about everyday emergencies called in by citizens. Drones are small scale, aircraft that are remotely controlled and provide video recording and/or streaming features. We have chosen to explore drones given their likely ability to provide important contextual information about an emergency situation [20]. For example, if an emergency is called in to a 9-1-1 call centre, one could imagine a drone flying to the emergency (either automatically or controlled by an operator) and providing a birds-eye view of the situation and sharing it with 9-1-1 call takers and, subsequently, first responders. Such a scenario has the potential to provide first responders with additional information such as the overall condition of the emergency and specifics of the location that a 9-1-1 caller may be unable to provide. In our work, we have chosen to focus on *firefighters* as they handle and respond to a range of emergency situations, including car accidents and hazardous material situations, in addition to fire response. To date, there has not been any investigation into how drone systems should be designed to best match firefighters' needs when responding to 9-1-1 emergency calls nor the benefits and challenges that might be raised by citizens about drone use during these situations.

We explore this topic through an interview and scenario-based study of emergency situations with firefighters and people who have experience in calling 9-1-1 to report emergencies. Here we focus on 'everyday emergencies' such as automobile accidents, fires, and injuries that a citizen might call in to 9-1-1, as opposed to disaster response, crisis management, or search and rescue. Such everyday emergencies tend to happen more frequently and are not explored in the related work when it comes to the use of drones. Our goal was to answer several research questions. For firefighters, how might firefighters make use of drone footage in an emergency? And, how should drone systems be designed to aid firefighters during an emergency? For 9-1-1 callers, what benefits and challenges do they feel exist for drones that capture video of an emergency situation? Together, our study represents a form of requirements analysis where we wanted to understand how to design drone systems based on firefighters' needs and the social implications and concerns that everyday citizens might have about surveillance and privacy.

Our results show that drones could provide a number of benefits to 9-1-1 callers and firefighters, including knowledge of the context of an emergency, which could save valuable time. Drones can be thought of as 'non-human firefighters' which have the ability to reassure people that 'help is on the way' and provide additional perspectives to the firefighters to help them size-up an emergency scene. Privacy and surveillance were largely not an issue in our study for participants unless they were at fault for an incident or doing something illegal. Together, these results illustrate design opportunities for emergency response drones with an emphasis on designs supporting trust by the public; communication between dispatchers and those on scene; appropriate and useful camera work; and multiple drones and possibly indoor drone usage.

2 RELATED WORK

In North America, placing a phone call to the number 9-1-1 has been the primary way to report emergencies for several decades [44]. Yet the reality is that such calls can create miscommunication, mental stress, and ambiguity [17,28,30,37]. A lack of information from callers might make it more difficult for call takers to decipher the nature of a situation (e.g., medical symptoms of an injured person). We also know that call takers prefer speaking to the person requiring the emergency service directly to get the most accurate information [17]. Other difficulties include hoax 9-1-1 calls, calls from people with mental impairments, calls from deaf or blind people, and callers not being able to accurately describe the situation (e.g., knowing how to describe specifics of a fire) [17,27,35]. Callers sometimes feel like they are not being heard properly by the call takers of emergency services which can lead to frustration and hostile callers [37]. Given these challenges, research has shown that if the call takers were able to see what is actually happening in the scene instead of being completely dependent on callers, call response may be more efficient [27,35].

There have been some investigations of next-generation technologies for emergency response. For example, studies have explored the benefits and challenges associated with people using video calling (akin to Skype) to talk with 9-1-1 call takers/dispatchers [27,35]. Video calls where seen as being valuable in cases where the caller had difficulties describing an emergency [27,35]. They were also seen as being valuable for firefighters as a part of scene size-up, detecting hazardous materials, information accuracy, providing instructions to the caller, and avoiding miscommunication [27,35]. Yet there were challenges in capturing the 'right' video, seeing video of gory/traumatic situations, and supporting callers who sometimes did not want to be shown on video because of privacy concerns [27,35]. Such privacy concerns are found more broadly for video streaming in public settings [8,36] where people may not react positively to being captured on camera [7,28,31,36] and in unfavorable circumstances [9,16,23,29]. While there is literature around video calling for conferencing and emergency services, there is a lack of investigation into the benefits and challenges associated with using video-enabled drones for everyday emergencies and how such systems should be designed.

Literature on public surveillance systems such as closed-circuit televisions (CCTV) points to the possibility of invading the public's privacy [15,18]. Yet many people are still accepting of CCTV surveillance despite the possibility of privacy breach [15]. Typically, people's acceptance is based on them being unaware of the capabilities of the surveillance system and the usage of the information [18]. For these reasons, we also explored the privacy and safety issues associated with drone surveillance for emergency situations in our study.

When firefighters travel to and attend to an emergency they receive textual information through a Computer-Aided Dispatch system in addition to key information shared over radios [27,41,45]. Firefighters attend emergencies ranging from fires to hazardous material incidents to motor vehicle accidents [21]. They size-up the scene upon arrival [19]. Information is relayed in a

hierarchical order from high ranked officers to subordinate officers over radio [11,19,39]. Paramedics depend on their workplace experiences and tacit knowledge when making decisions of how to attend to an injured person [45]. Previous research looked into the necessity of information sharing between first responders (firefighters and police officers) and emergency control centres during emergency situations [24]. Results showed that first responders valued seeing a situation for themselves [24]. However, the focus was not on the use of drones as a medium to share information. Mobile applications have also been explored to share information with call centres and found to be valuable [4]. Other mobile applications explored text messaging between firefighters for communication where a historical record and pre-defined messages were valuable [5].

Drones have the potential to be effective for emergency situations by providing a bird's eye view [20]. A study suggests that drones can be socially adopted and accepted [12]; however, a lack of regulatory frameworks calls for an investigation into how drones should be used [22]. Concerns related to drones for public services involve using them as weapons [42]. Studies have also explored how public acceptance of drones improves when there are no weapons associated with a drone [6]. Some firefighters in the USA are using drones to help them figure out how to put out fires on the scene [48,50]. Drones have also been used for the assessment of post disaster scenes [2]. Automated External Defibrillator (AED) equipped drones have been studied to enhance cardiac arrest response times [14,32] and drones have been studied to transport blood and medical supplies to hospitals [38]. Drones were studied for search and rescue operations in mountains [34] and architectures have been developed for utilizing drones in search and rescue [10,26]. Here they have, again, been shown to be valuable for saving lives by providing medical supplies and locating a lost person.

People's privacy perception of drones was explored by Yang et al. [43] who found privacy concerns around inconspicuous data collection and inaccessible controllers of the drone. This work explored civil, government, and recreational drones while our study aimed at understanding people's perception of drones in emergencies. Chang et al. explored privacy and security issues involving drones [13]. While they did not find any new concerns, they found out that the drone design itself can shape people's privacy and security concerns. Other work in this area explored how the registration of drone owners could reduce people's privacy concerns [47]. People's privacy concerns often get trumped by safety issues and sometimes privacy issues regarding drones could be termed 'overstated' [46]. Uchidiuno also found similar results while exploring privacy expectations in people [40]. They found that technology that prevents data collection in sensitive situations had the greatest impact on people. Given this prior works we were motivated to explore and find out the design opportunities for emergency response drones.

3 USER STUDY

We conducted an exploratory study with 9-1-1 callers and firefighters to understand how firefighters could make use of drone footage during everyday emergencies; how drone systems should be designed to aid firefighters during such emergencies; and what benefits and challenges everyday citizens feel exist for drones that capture video of an emergency situation. Our study was approved by our university research ethics board.

3.1 Participants

We recruited 20 participants in total through snowball sampling (word-of-mouth), social media (posts on Facebook), and contact directly with emergency response centres within our city. Participants were in two groups.

1. Everyday People: First, we included everyday people who had previously called 9-1-1. This group included 6 males and 6 females with an age range of 18 to the late 60s. Four participants lived with children and partners, one participant lived with parents, four participants lived with their partners, and two participants lived alone. All participants knew what a drone was and five reported that they had used one before. Participants called 9-1-1 an average of 4.2 times (median=2, range 1 to 15). Three participants called for all types of emergencies (medical, fire, police), two called for medical and fire emergencies, two called for only a fire emergency, one called for medical and police emergencies, and four participants called for only medical emergencies. The fire incidents involved house fires, vehicle fires, and a gas leak. Medical emergencies involved someone having a stroke, panic or anxiety attack, drug overdose, asthma attack, and injury. Police emergencies involved robbery in stores, domestic violence of neighbors, and threats at work.

2. Firefighters: Second, we recruited seven firefighters. These participants had an age range of 36 to 65 with firefighting experience ranging from 5 to 40 years (average=26.5 with median=31). Two participants had extensive experience with using drones for emergency situations; they operated and used drones for investigating

emergencies on site. Our participants were ranked Fire Captain, Assistant Fire Chief, Deputy Fire Chief, Chief, Civilian member of the police, and network engineer for operating drones. While not our direct demographic target, we were contacted by a police officer during our recruitment period because he had extensive experience in using drones for emergencies. He was a civilian member of the police whose specialty was technology. One of his roles was to take requests to launch drones for helping police with emergencies. Given this experience, we interviewed him as well. This meant, in total, we conducted the study with eight first responders (7 fire, 1 police).

3.2 Method

We conducted semi-structured interviews with each participant. Interviews were conducted in-person with local candidates living within Metro Vancouver, Canada. Participants living outside of our city, but within Canada, were interviewed through a video communication system (Skype). We audio-recorded and took notes to summarize each of the interviews. Interviews lasted between 25 and 75 minutes. Questions were different for 9-1-1 callers and first responders given their backgrounds and differing needs. We structured the interview in two phases:

1. Context: The first phase of the interview focused on the experience of people who called 9-1-1 for emergency services and the recent calls that the first responders attended. We asked them to describe these situations to provide us with knowledge of their experiences. After that, we asked all participants, if a drone was able to share video of the emergency with a 9-1-1 call centre, "What should it capture?" We also asked, "How would you feel about using a drone for this situation? What benefits do you see? What challenges might emerge? What concerns would you have, if any?" Depending on their answers, we probed with additional questions.

We found that when recruiting and conducting our study that participants who called 9-1-1 more often (more than 4 times) could not remember every call situation. Therefore, when interviewing them they talked about the situations that they remembered within the previous five years. Participants tended to describe these situations quite vividly, thus, it is likely that their reflections of the events were mostly accurate. Yet our results do come with the caveat that all participants were talking about reflections and memories of the past where recall may not be entirely accurate.

2. Video Scenarios: The second phase of the study focused on understanding participant reactions to actual drone-like video footage of everyday emergencies. We told participants that they could imagine that a drone flew to each emergency location once a situation was called into a 9-1-1 call centre. Video would then be streamed from the drone to the call centre for call takers and dispatchers to see. This video footage would then, in turn, be shared with firefighters who were traveling to the location (viewing it in their firetruck) as a means to prepare them and help deal with the emergency situation. Firetrucks in our city all contain a laptop in the front cab that shows textual information about the emergency the firetruck is traveling to. For the most part, the use of drones was described as being something that would occur outside, where drones could fly within public spaces. Yet we also told participants that they could imagine more futuristic situations where a drone could possibly fly indoors to, for example, share footage of a medical emergency (e.g., a fall, a heart attack).

Because we could not engage participants in actual live emergencies, we used seven video clips of emergencies that were publicly available on YouTube[1]. We edited each video clip to be 30 seconds in length. The videos were categorized and purposely selected to be in four groups representing a range of emergency situations: fire, hazardous material, vehicle accident, and injury in an apartment. Four of these videos were actually captured by a drone while three of the videos were filmed with a smartphone. We used the smartphone videos to provide a different camera perspective of an incident in order to gauge reactions from participants. The videos had diverse characteristics such as providing aerial views, ground level views, and a combination of both views. We also included linear camera movement, circular movements, semi-circular movements, and a combination of linear and circular movements. Views were a mixture of close up and far out views. Given the exploratory nature of our study, we did not control for which videos contained which type of camera footage as might be found in a controlled study. Instead, we purposely included a large amount of variations in the video footage to gauge people's reactions to varied situations and camera work. Trying to control for different types of video footage in the scenes would have meant we could explore far fewer variations and scenarios.

[1] Scene 1: Fire From Top - https://www.youtube.com/watch?v=oq58yfxjrWA
Scene 2: House Fire Close Up - https://www.youtube.com/watch?v=uP4FazhKqgg
Scene 3: Apartment Complex - https://www.youtube.com/watch?v=6PYL1nCwpE0
Scene 4: Hazmat From Ground - https://www.youtube.com/watch?v=FG1LGKieTxY
Scene 5: Hazmat From Top - https://www.youtube.com/watch?v=yBBMnsf2DaY
Scene 6: Accident Far Out - https://www.youtube.com/watch?v=Agr5_uRDCk8
Scene 7: Accident Close Up - https://www.youtube.com/watch?v=Xj1tOPGK8zg

We started the interview by showing each participant a ten second video of a high-end commercial drone so they would understand what a drone was, if they were unfamiliar. Then, we showed them each of our video scenarios one-by-one and asked participants a series of questions about the video. Videos were shown in the order presented in the footnote[1], from left to right, and top to bottom. Again, our study was meant to be exploratory and not controlled, so we did not randomize the order of scenes. Controlling scene order and using all possible permutation orders would have restricted the number of scenes we could show participants. When participants viewed the scenes, we wanted to understand what benefits they thought the drone would offer and how comfortable they would be with the drone capturing the video footage. For example, we asked people who called 9-1-1, "How would you feel about the drone if you were the victim in this incident?", "How would you feel if this incident occurred to [a neighbor, a friend, a family member, a stranger]?", "How would your reaction change if the drone captured audio too?" We also asked questions about drone movement and control, e.g., "Would you like to suggest any drone movement patterns?", "Do you think the drone should be autonomous or should it be controlled by a human?", "When do you think the drone should stop capturing the scene?" Lastly, we asked about possible privacy and safety issues, e.g., "Do you have any privacy or safety concerns?" For firefighters, we were interested in understanding how the drones might benefit their work, what challenges they would introduce, and how drones should best be designed to support their work needs. For example, we asked, "What information can you gather about this situation with the current drone footage? How would it help you, if at all?", "What can you not see that you would like to see?" The remainder of the questions were similar to the ones we asked the 9-1-1 callers as to whether they had safety or privacy concerns, what cameras views were best, etc. After the video questions were completed, we asked all participants where they felt the drones should be located, how they should appear visually, and what kinds of situations they thought drones worked best and worst for.

3.3 Heading Data Collection and Analysis

All interview data was transcribed and analyzed using thematic analysis to draw out main themes. The transcripts were read iteratively by one researcher to initially code the data to find similarities and differences across participants. Through frequent meeting with a second researcher, we explored the data for categories and central themes. For example, codes included "benefits", "suggestions", "audio", "two-way communication", "privacy", "safety", "appearance", "drone control", "camerawork", etc. We found groups of themes related to the benefits and basic usage of drones; challenges related to privacy, safety, the limitation of drones, and needs of callers; drone control; appearance; and, initial locations of drones. We detail each of these groups next. For quotes, we refer to each caller by P# (P followed by a number) and each first responder by F# (F followed by a number). For additional anonymity, we decided to keep the age and gender of the participants undisclosed. For simplicity, in our results we refer to 9-1-1 callers as simply callers, and the firefighters and police officer as first responders. In cases where fire fighters or police responders gave different thoughts, we describe them separately.

4 BENEFITS AND USAGE OF DRONES

Our first responder participants talked about how they already used drones for a limited number of emergency situations. For example, several fire departments used drones to investigate incidents such as large-scale structural fires and wildfires. Drones were also used for police emergencies such as search and rescue, and crime investigation. Drones were not yet used for everyday emergencies that were typically called into 9-1-1 call centres, given the newness of the technology and a lack of understanding for how drones could best be used and designed for these situations. The police officer described drones as being cost effective compared to a helicopter and capable of capturing images in a high resolution (4K). According to him, drones also saved time since getting the drone to an emergency scene was faster than finding a helicopter pilot and traveling there.

All participants talked about a number of benefits associated with using drones when they were shown the seven emergency scenes, though some situations were seen as being more useful than others. We discuss these in detail next.

4.1 Fire Emergencies

All participants felt drones were useful for fire-related emergencies when they watched the two fire scenes (Scenes 1 and 2). Callers felt drones would be helpful in these kind of situations by providing call centres and first responders with a full picture of the situation. Callers talked about other benefits including locating the nearest fire hydrants, ensuring an appropriate amount of resources were sent, and firefighters being able to detect the location much faster by locating the drone. While callers were speculating about these advantages, the overall benefit was

that callers felt an increased sense of trust in the first response being received because of the drone and its capabilities. They perceived the additional capabilities as enhancing the emergency response team. For example, callers talked about having mental piece of mind when they saw the drone, knowing that help was coming and 9-1-1 call centres knew more details about the situation.

> *I would be happy because I'm comparing it to the situation when there is no drone to capture anything. So, it's always better that they're getting more data so they can plan better to help me. -P4*

Firefighters found the drones to be useful in fire emergencies as a tool for size-up. They all analyzed the videos and discussed how they would pre-plan to handle emergencies such as what was shown to them. For example, firefighters talked about how they would position their apparatus to contain explosions, create rescue plans, park their vehicles, establish a safe-working zone, locate fire hydrants, etc. While watching one of the fire videos, F6 said:

> *That would be what we would call a defensive fire, so we're not going to go inside that building obviously because it's completely involved in and fire. Unfortunately, anybody inside the building would no longer be alive and that's a shame, but at least it informs us what we could do for other people. -F6*

One firefighter pointed out how he saw a truck near the building in the drone video, which gave him a sense of the size of the structure on fire. He thought these visual indicators would be useful. Firefighters also talked about how they often lacked a view from the top. They found having an 'eye in the sky' very useful and it would save them valuable time considering the time sensitive nature of the emergencies. They described how they often sent firefighters on the roof with a ladder to get a view from the top. Using a drone instead of a person or a helicopter would be beneficial in terms of safety, time, and cost. However, firefighters felt they would not need drones for small fires, i.e. a kitchen fire.

The police officer talked about how drones could be helpful in similar situations to move people and property (vehicles for example) to a safe location and help firefighters gain strategic information.

4.2 Hazardous Materials

In situations involving hazardous materials (Scenes 4 and 5), callers thought the drones would be useful for capturing information from locations where it might be harmful for humans to go. Callers were satisfied as long as the drone would be there to 'help.' Firefighters found the drones to be the most useful in hazardous material situations. Drones could help firefighters manage the site better, ensure public safety, and manage traffic because they'd be able to see any backups or patterns. Most firefighters emphasized the drone being able to detect placards/signs on vehicles involved in such incidents to find out the characteristics of the chemicals that might be spilled. They also said that drones should have sensors that would be capable of detecting the nature of any chemicals.

> *I need to identify the markings on the vehicle so that I can contact the carrier or see the placards. -F2*

Other benefits included determining the appropriate amount of resources to send. Firefighters pointed out that sometimes too many resources might exacerbate a situation. They also talked about displaying how long the drone had been recording the scene to determine their strategy. Longer time periods might mean differing chemical reactions or problems. The police office said that the drones could be useful for traffic management.

4.3 Vehicle Accidents

One of the accident videos demonstrated a situation where there was no injury and the situation was stable (Scene 6) and, in another video (Scene 7), there was a trapped person inside a vehicle. Callers felt drones could help first responders regulate traffic, provide instructions of what to do next (described more in a later section), capture information for insurance claims, and illustrate that someone was coming to help the victims. However, two callers said they would not want the drone to be at the scene, if the accident was their fault.

> *I'm scared to be identified as it was my mistake. That makes me bad, but obviously that's what I want. If it's going to police, I don't want to be identified in a video. -P9*

Firefighters felt that in car accidents without any injury, drones could help inform dispatchers to send the appropriate resources to a location. In situations with injuries or trapped victims, they wanted the drone to monitor the situation from a distance which is what they call 'doing the outer circle.' The outer circle is normally done by a person from a distance to find out if there are any broken car parts or injured people. Firefighters felt that if the drones could do this for them, they would be able to focus on the injured person. They cautioned that they did not want drones to get too close to the scene once they

arrived, as they could get in their way. The police officer talked about detecting witnesses in such scenarios with the help of drone footage and how they can be helpful for insurance claims.

4.4 In-Home Medical Emergencies

After seeing the video of the drone flying out to an apartment complex with a medical emergency (Scene 3), participants had mixed feelings about drones for medical emergencies. Callers who had their own children at home reflected on their experiences and thought drones would help assess the severity of the incident. Of course, drones would then need to be able to actually enter an apartment or house, which would be difficult with present-day technologies. Other participants did not think drones would be able to help in medical emergencies. Instead, they talked about other information that they thought might be more useful for call centres and first responders to know about, such as physiological data. This information was not something they thought drones could capture.

> *I would want them to know the intensity of my anxiety or whatever at that moment, intensity of my distress and my physiological readings, like my heart rate and breath being shallow and things like that. That I can imagine sharing with them, but, but my surroundings, that's, I don't see anything about my surrounding. -P2*

Two callers talked about using Google Maps instead of drones to get traffic details and location specifics. Three callers thought drones would be able to find out the entrance to apartment complexes.

Firefighters found drones to be useful to get traffic information for in-home medical emergencies. This could help them to travel effectively and efficiently to the location. Yet one firefighter was concerned that the drone might confuse them if it was not pointing to the correct entrance or multiple apartments or homes were seen in the drone's video. Firefighters suggested that having a building number on the roof would help them to detect the correct building. For example, while watching Scene 3, F5 said:

> *What we understand from that is there are two significant entrances to buildings. We're not sure which one is the right one depending on our mapping and things we have in the truck or in the ambulance or whatever it is we're responding with. -F5*

5 DESIGN NEEDS AND CHALLENGES

Within the aforementioned situations, participants talked about ways that drones would need to be designed and realized in order for the benefits of drones to be achieved. They also talked about further challenges that might arise related to privacy and safety. We describe these results next.

5.1 Appearance and Location

First, participants talked about emergency response drones in ways that made them visually distinct from existing commercial drones that one might buy in a store or be available to consumers. Callers suggested appearances for emergency service drones that were different from existing commercial drones in order to make them stand out and be identifiable, much the same way that a fire truck clearly shows the public it is for handling emergencies. Four callers suggested using lights, while others suggested using bright colors. There were suggestions for drones to have design patterns like a fire truck or a police car. The appearance of the drone was important to callers because they wanted to be certain that the drone was sent for emergency services and there to help them, as opposed to being a drone sent by a stranger or non-trusted figure.

> *The drone color should be prominent because when I am in an emergency, I am panicking and it's going to be hard for me to know if the drone is from 9-1-1. -P2*

Firefighters and police also suggested similar design patterns in terms of colors and appearance.

Six callers suggested drones should be able to go inside of a house or a vehicle in case of emergencies. This meant that they would need to be very small in order to maneuver through doorways and around obstacles. Such a small size could exacerbate the need to make the drone's appearance easily distinguishable and understandable at a distance. Callers also suggested drones that were tolerant to heat and possibly resistant to fire.

> *It would be very hard to find out my apartment for the first time. If the drone could go and find where is A100, that would be very useful. –P3*

Firefighters suggested using different types of drones for different scenarios. For example, they felt that drones equipped with sensors to detect and analyze different chemicals would be important for situations involving hazardous materials. The caveat is that, while important, the 'right' drone would need to be sent out to an emergency

and knowledge of the specific situation would need to be known in detail *a priori.*

> *You may also have something like a gas sensor on it [drone] to determine, uh something that's being expelled from the tanks. -F2*

First responders thought that 'mini' drones could be useful in certain scenarios where the drone could go inside a building and figure out if there was any people inside. By 'mini' they referred to drones that were about the size of one's hand.

> *I know some of the mini drones can form a swarm and do the mapping of the layout themselves and they can interact with each other. They can work great to rule out if there's anybody who is inside the building. -F7*

Callers felt drones should be located in places that already represented 'authority' and emergencies, such as at firehalls, police stations, and the rooves of hospitals. Callers felt that it was important that drones be located where they could see them in order to create a sense of safety. Three callers felt drones should be strategically located throughout the city in order to be able to reach any location in the shortest time possible.

> *I think you should divide an area vertically and horizontally and calculate how many intersections you need to locate the drones so that they can go anywhere in the desired time. -P1*

First responders thought that firehalls were a good place to locate drones since firehalls were already strategically located in a city such that they are in close proximity to most areas. However, there were noticeable limitations described for cases where emergencies occurred on highways or railways that might be outside of a city and away from firehalls. Some noted issues with flying near airports, which we talk about more later.

> *So, your main highways, [north of the city] seems to get a lot of rescues, I think you need to do a risk hazard evaluation to determine that. And then there are the issues about drones flying around airports. -F2*

5.2 Capturing the Scene

We talked with participants about the camera views and flight paths that they thought would be ideal for drone footage of emergencies. All participants except two callers talked about the drone circling around the emergency scene from a high height to provide an overview of the incident. In some cases, callers suggested a combination of high views and close up circling around a scene. Participants felt that multiple cameras could be useful to capture a scene from all sides in a short amount of time, though some recognized associated cost issues.

> *I would want the drone to give me a bird's eye view and then come down to see if there are any victims. -P8*

> *I guess if there's multiple drones, I don't know if that would have got different angles at the same time as opposed to just one. Of course, that's probably more expensive. -P6*

Firefighters wanted the drones to do a size-up of an emergency scene for them. That is, they wanted the drone to approach a structure from the front side and rotate around it clockwise. The height of the drone depended on the structure where they would capture from a height of several hundred feet if it was a large structure. If it was just a house, they suggested capturing it from ~50-60 feet above. In the case of hazardous materials and car accidents, firefighters felt that the drone had to fly low and circle around the incident from a safe distance. This would allow them to see how many people were injured and get a sense of what the injuries might entail. When drones are dispatched to residences, they felt that it would be helpful for them to fly to a building's entrance or show multiple entrances to them. The police officer also talked about circling around the scene.

> *Depending on the scenario, I would do a 360 from 10 feet, 30 feet, 60 feet to provide additional perspective to investigators. -F1*

Thermal images were pointed out as very important by the firefighters. Thermal images have the capability to provide heat signatures and possibly show if any humans are inside a structure.

> *We would use the thermal camera to see if this house on the other side of the street is about to catch fire or if there is someone inside. Sometimes the thermal cameras show temperature and we could act on it. I think that's very helpful. -F6*

Callers and firefighters both thought that drones should support a combination of autonomous and manual camera control and flying features. Callers felt there were many possible scenarios that could happen during an incident and a drone may not be smart enough to capture everything that is necessary on its own in an automated fashion. Callers were more comfortable with a drone that combined

human control with automated flying. Again, this created feelings of trust in the technology and the emergency response.

> *If the drone could let him [pilot] know, "I can't get in, there's a fence" or "this place is too hot, I shouldn't enter", it would be very helpful and also keep the drone from getting destroyed. -P1*

Firefighters generally felt the same way and preferred a combination of autonomous and manual control features. However, they felt it was more important to gain manual control of the drone once they arrived on scene. They could then look at specific things of interest.

> *It should launch automatically, do a 360 for us in clockwise direction starting on the alpha side of the building, that is the address side of the building and from that point on, it should be manual. -F1*

5.3 Two-way Communication

We probed participants about the possibility of drones streaming or recording audio in addition to video. Callers suggested that drones should not only have audio, but that there should be two-way communication as well. Callers thought they would find it comforting if the drone was able to provide instructions to them at the scene. This might be done, for example, by a 9-1-1 call taker, dispatcher, or a first responder, who could speak through the drone using a form of two-way audio system. This builds on previously reported ideas that callers saw the drone as a way to comfort and help them, and not just provide video surveillance data. Callers pointed out cases where the situation could get chaotic or they might feel panicked. Here they felt that drones could be used as a tool to help calm them down.

> *I think it would be helpful in terms of maybe like broadcasting a message for everyone to like get clear, move out of the way, help is on the way or even providing instructions like from the situation like CPR. -P10*

That said, some participants thought that audio or two-way communication could distract firefighters from doing their duty and might reduce the resources available for dealing with the actual situation at hand.

> *I would be worried, you know, it could take a person or two and maybe they don't have that many people to attend to the victims. -P7*

Firefighters felt that audio or two-way communication might cause information overload if call centres were trying to communicate with them through the drone. However, they found value in being able to talk with dispatch centres in case they had questions with them. Some firefighters and the police officer thought that audio may not be useful because the sound could be drowned out by the drone's propeller noises or not be heard if the drone was high in the sky.

> *There's conversation happening in the firetruck and we're talking on the radio, we're listening to the radio. So, my initial reactions in this application, likely not for audio. However, if it was available and we could, you know, push, push a button and raise the audio. -F7*

5.4 Privacy

We anticipated that callers may be concerned about drones being used as a form of public surveillance, especially if they were bystanders of a situation and the emergency did not involve them directly. Yet all but two callers did not have any privacy concerns about drones capturing an emergency scene. Callers were willing to accept that emergency service drones were around and used because of the emergency nature of them. This sentiment held true regardless of whether the emergency incidents involved themselves, their family, friends, or strangers.

> *When I am going inside an operation [room], I don't think about my privacy. I only think about my life. I think these are similar. To me, life is more important than privacy. -P1*

Two participants expressed concerns about a drone getting too close to their property and capturing people in a situation where they would not normally want to be captured. They also worried about a drone coming into their home and capturing the inside of the house because their physical appearance and activities may not be favorable at that moment. They felt this could be traumatic for the victim. Other concerns related to capturing an apartment included the condition of the victim and other activities going on. For example, if someone calls for a drug overdose, being captured by a drone might be harmful for them in terms of law.

> *I don't want the drone to capture my apartment. Because you never know what they are doing inside. There could be police with them and it will look bad. -P11*

Other than those types of situations, callers did not have any privacy concerns provided that the drone was for emergency services. Participants were most concerned

about privacy if they were bystanders or at fault in a situation.

Firefighters thought that there should be regulations for capturing public information with drones. They felt that captured information should be stored in a secured manner and not end up in public spaces, e.g., online. They pointed out that if a firefighter takes a picture of an emergency, it becomes public property and people have the right to access that information. There were also concerns with unintentional collection of data.

> *There is so much private information that you may gather, not that you're trying to gather that but you may invade privacy, it starts to become an overriding problem. Um, I think this is another issue, not that it would stop you from using it, but when you have that much data, how do you have these stored safely, securely. -F7*

In addition, firefighters expressed concerns with seeing drone footage containing graphic scenes involving death and damage to a victim's body. They felt like this type of footage should be shared only with the first crew members that arrive on the scene and others should be protected from seeing such footage. Other concerns involved seeing people getting injured or dying when firefighters cannot do anything about it. They felt these types of situations could cause them to have post-traumatic stress disorder.

> *If someone is sitting on the balcony and dying, we are seeing it as we go to the scene, and we can do nothing about it, we don't want to see it. If someone dies, that's a very bad day for us. I don't want to see that and I want to protect my crew from seeing that. – F8*

5.5 Safety

As one might expect, participants had several safety concerns with drones. First, there were concerns by both callers and first responders about hackers infiltrating the information and using it to 'create chaos.' Three callers were worried that the drone might hit their motor vehicles in which case they would need to be compensated. There were ecological safety concerns with the possibility of drones interfering with flight patterns of birds or destroying bird habitat.

> *If hackers get access to the drones and causes interruptions to stream video to 9-1-1 people, it would be very dangerous and they could learn from the videos how to create situations out of control. -P1*

Firefighters talked about how it is important to have a flight plan and make sure drones do not interfere with airplanes. They felt that it was necessary for trained firefighter pilots (as opposed to inexperienced firefighters) to handle drones around an emergency otherwise the drone could get destroyed. There were also safety concerns related to the drone falling on people accidentally.

> *We fly this into the fire zone, it gets impacted by the fly ash and fall on someone and hits them. No one wanted that to happen. And if we do this daily, it's going to happen. -F6*

One firefighter was concerned that if drones did portions of their work for them (e.g., scene size-up), firefighters may begin to neglect their own duties. For example, physically walking around the scene to do a size-up is mandatory for firefighters, given current policies, even if a drone does it for them. There was concern about the drones recording video for future review since firefighters' decisions and judgements on the scene might be questioned by people or investigators. They pointed out that, when on the scene, they do what they think is best and have to make decisions very quickly.

> *So, it would be difficult, I think, you know, if somebody had possession of footage after and we ended up in court, it would be a lot of questions and sometimes those questions would be healthy and sometimes those questions will not be healthy. -F5*

6 DISCUSSION

Our study points to a range of design possibilities and challenges associated with drones and everyday emergency response. We explore these next.

6.1 Drones as a Trusted Companion

First, when callers talked about the emergency situations presented in the videos, they described a great deal of trust associated with the drone and what it represented, an authority figure who they equated with help. Prior literature has explored people's social acceptance of drones in situations not involving everyday emergencies [12,13,40,43,46,47]. Our study moves beyond these acceptance models and situations to illustrate that people even begin to see drones as somewhat of a companion in an emergency situation. For example, just seeing a drone coming was seen as being comforting. Compared to literature around public video streaming [15,28,29,36], we see a high level of acceptance for drones with video cameras, providing that they are streaming emergency situations. This was regardless of whether participants

were a victim, family member, friend, or a stranger/bystander to an emergency. Issues only arose when people thought about the possibility of doing something that may be considered illegal, or if they were possibly at fault for an accident.

When it comes to the design of emergency response drones, it becomes clear that they should be recognizable as such: systems associated directly with help and emergency response. Participants suggested that drones should feature a prominent appearance that is easily distinguishable from commercial or recreational drones. If drones are clearly visible as emergency response drones, then people will likely trust them and value the work that they do for first response. Of course, there may be people who try to avoid drones if they are doing something suspicious or illegal activities and a prominent visual appearance may make such avoidance easier. This may create a need to design non-identifiable drones, which would likely raise concerns about privacy. Firefighters pointed out that it would be beneficial if drones could have different functionalities to detect chemicals or components in the air, detect heat signatures, access indoor locations, or go into challenging locations. Having all those functionalities in a single drone could be quite challenging to design, at least currently.

Callers also talked about drones in a way that somewhat personified them as emergency responders in and of themselves. That is, they saw drones as a tool that might allow them to talk with actual 9-1-1 dispatchers or even first responders where the drone would act as an embodiment for a person. This represents an interesting design opportunity and one that could profoundly change the workflows and capabilities of emergency response. Thus, it requires very cautious design and interactions with many different stakeholders to understand if and how such designs would work and what workflows would need to be changed within emergency response protocols so that work processes stay efficient. For example, two-way communication through a drone could create information overload challenges for 9-1-1 call centres and first responders. It may create new duties for dispatchers, thereby requiring additional staff to handle large volumes of calls. Yet the benefit is that two-way communication through a drone could present valuable new opportunities to provide instructions to people at the scene of an emergency, or mechanisms to calm people who are in distress. In turn, this may affect 9-1-1 call taking protocols. For example, the questions being asked to callers may need to be updated to reflect new ways of acquiring information.

6.2 Capturing an Emergency

Capturing an emergency situation with a drone starts with the challenge of initially locating drones and where they start their journey from in order to reach an emergency location. Callers valued drones placed in areas of authority that resonated with notions of help and existing emergency services, e.g., fire halls. This builds further on the notion of trust that citizens would place in emergency response drones. Firefighters pointed to the pragmatics of ensuring drones are close to as many locations as possible. Once arriving at a scene, we see further design requirements around the camera work needed to adequately capture the scene. Desirable views involved a mixture of close-up and far-out video, with various flying patterns to size-up the scene, gain broad contextual awareness, and monitor situations on the go.

Arguably more interesting is the way in which such views might be obtained. We probed participants about autonomous vs. manual control of drones and saw the need for both. From the perspective of firefighters, this was for pragmatic reasons and the ability to ensure the right information was captured. From the perspective of callers, again, the element of trust arose where the combination of autonomous flying and manual control helped create feelings of trust. Based on this, one could then imagine autonomous drone features that might, for example, cause the drone to fly to a designated location and first capture a 360-degree view automatically. Image processing software might mark important objects around the scene, e.g., a fire hydrant or damaged vehicle. 9-1-1 call takers or dispatchers might then be able to take control of the drone and capture footage of particular interest to them. Firefighters might be able to communicate with these individuals and request additional footage. Again, one would need to be cautious about changing workflows and creating additional work and possibly information overload. Such capabilities may create more work for dispatchers and firefighters, information overload, or distraction from existing tasks. Additional training of how to understand the information provided by a drone could also be needed.

Within these drone behaviours and camera work, privacy concerns were somewhat minimal for participants, at least in the basic cases of drones being flown outdoors and capturing somewhat mundane details about an emergency, e.g., its location, who is around, what is wrong. The sense of an emergency's needs superseding privacy was evident. Yet some participants suggested more complex scenarios involving multiple drones, drones that could fly indoors,

drones that might be small and highly mobile, and drones that recorded video footage rather than just being streamed to 9-1-1 call centres and first responders. While safety issues and drone flight paths are clearly an issue in the outdoors, especially around airports, issues around indoor flight, swarms of drones, and recording video footage create more contentious situations for emergency response drones. This raises legal issues for both callers and first responders, and possibly additional stress with seeing footage that may be considered gruesome.

Overall, this suggests design opportunities for future work to more deeply dive into how drone systems can be designed for these more complex situations. Participants saw value in such advanced drones and drone capabilities, but clearly there are issues that designs will need to mitigate. For example, how can drones fly safely indoors with large amounts of objects and people around? Do privacy concerns increase when drones become even smaller and are less visible, or when they are part of larger swarms of drones? There are also likely situations that design work will not be able to address. These will involve additional training (e.g., how does one fly swarms of drones?), public policy (e.g., where can drones fly?), and updates to operational workflows (e.g., who is responsible for flying drones?). In addition, there are ethical issues that design may not be able to easily address. For example, challenges arise around capturing video of people in public settings and capturing emergency service seekers who may not want to be captured (e.g., people who may be at fault during an accident). This juxtaposes feelings of surveillance with the desire to help people and use drones 'for good.'

6.3 Limitations

While our study presents promising opportunities in this design space, there are clearly limitations to our study. Callers reactions were based on the video scenarios as opposed to real life situations. Firefighters could also view the videos and react to them in a much calmer environment than they would typically be used to during an emergency. Our video scenarios may also have somewhat limited participants' imaginations and reactions to emergencies because we could only choose a narrow set of scenes. We tried to pick a variety of scenarios that firefighters generally get called to in order to mitigate this limitation [30]. Videos were also shown to participants in a specific order as opposed to randomizing the sequence, which could bias the reactions of participants. Our study was conducted within Canada and it may be the case that participants' reactions are indications of the culture within the country more broadly. Firefighting and 9-1-1 calling practices may also be more specific to our country, though we do know that firefighting practices and emergency response is somewhat homogenous across Canada, the United States, and the UK based on prior research [17,27,30,37,44]. Together, these limitations suggest future work exploring additional reactions and thoughts from participants in other countries and cultures more broadly.

CONCLUSION

Our study explored how firefighters reacted to and thought about the use of drones for supporting first response work in everyday emergencies. Our results point to design opportunities for researchers and designers in this space around: a) designing drones to support trust by the public; b) designing to support communication between dispatchers and those on the scene; c) designing to support camera work including camera views and autonomous vs. manual control of drones; and, d) designs that support multiple drones and possibly indoor drone usage. In each of these areas, there are design opportunities but also design challenges. Our work draws out issues of how to design to support trust when people may have different views of when and how drones should capture video of an emergency, given that people are in different situations and the footage may affect them differently. There are also clearly implications for the workflows of first responders and firefighters if drones are to be included as part of their work. Ultimately, our work illustrates that drones could be thought of as valuable resources for first response, yet complicated design challenges are at play, some of which may not be solvable through actual design itself.

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