How Can Dog Handlers Help Us Understand the Future of Wilderness Search & Rescue Robots?

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***Abstract*— Wilderness search and rescue teams face challenges in hazardous environments. While robots show promise for these teams, their success depends on their ability to account for sociotechnical considerations, including human factors, as well as the organizational, economic, and emotional realities of search missions. We investigate these considerations through interviews with wilderness search team members who handle search dogs. These interviews reveal underexplored perspectives on awareness and uncertainty, the value of training experiences, team dynamics, and financial feasibility. Our findings motivate design recommendations for semiautonomous systems in the wilderness, yet also raise key questions regarding the role that robots can and should play in this domain.**

INTRODUCTION

Several years ago, "David" went on his first search and rescue (SAR) mission as a dog handler and ground searcher. Two young men had gone hiking and not come home – having mistakenly climbed the wrong mountain and gotten lost. David's dog wanted to go away from the team's intended search area and tried to take him up an adjacent peak instead—where the lost men really were. However, operations insisted that the team stay in the designated area.

Even as a new handler, David knew that environmental conditions favored his dog's senses. But despite his confidence and trust in his dog, David didn't advocate for the team to deviate from their search plan. Eventually, the lost men made it home safely on their own. But the experience taught David the life and death consequences of trusting his dog and communicating with his team.

Wilderness SAR teams, which differ from urban and disaster response teams [1], [2], are beginning to consider using robots [3], [4], due to their successful use in domains like urban [5], disaster response [6], [7], marine [8], and nuclear forensic searches [9]. This trend leads us to reimagine David's story if he had been a new robot operator instead. What experiences would have helped David build trust in his robot? How might his robot have communicated the need to move beyond the intended search area? Would David know the environmental parameters that affected his robot's abilities? How would David stay aware of his robot while attending to team logistics and wilderness hazards?

David's story shows why human context matters for wilderness SAR technology. Search missions environments are unconstrained and characterized by uncertainty, communication challenges, and life-or-death decision making. For robots to be successful wilderness search tools, they must not only move and sense under difficult conditions, but also operate with sensitivity to their human teammates—helping human users to build accurate Situation Awareness (SA), communicate effectively, and maintain calibrated trust in their robotic tools. Additionally, Robots must also function within the organizational, financial, logistical, and even emotional contexts that underlie wilderness search missions. In the intermountain region of the US, where many wilderness missions occur [10], teams are often composed of volunteers who accept a great deal of risk to their personal safety to participate in missions [1]. In this work, we examine how these broad factors are already mediating the deployment of another type of semiautonomous search-and-rescue tool: Search and rescue dogs.

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Human-animal teams → human-robot teams

Though working with an animal is not the same as working with a robot, compelling analogies to our relationship with animals can inform the design of semiautonomous technology. Like animals, robots can sense and move in ways we cannot, but have limited understanding of situational context [11]. Animal searching behavior has inspired the design of algorithms for autonomous navigation in SAR robots [12], and rescue robots at the World Trade Center after 9/11 were even organizationally classified as canine teams [13]. While there are important limitations to this metaphor [14], we believe that understanding wilderness SAR dog handlers' existing perspectives on communication, awareness, and trust in the context of their relationship with their dogs could serve as a compelling way to explore how technology might perform in a similar role.

We aimed to develop a rich understanding of how semiautonomous robots can be accepted, trustworthy, and successful with wilderness search teams. We explore this domain through interviews with wilderness search dog handlers. Our open-ended discussions with these domain experts reveal dimensions of the broader context of wilderness searches (such as training experiences, team financial operations, intra-team conflict, attitudes about technology, and the emotions at play during a mission) that may mediate the success of future technology deployment. By synthesizing these insights, we create design recommendations for semiautonomous robots, to better address searchers' needs for SA and calibrated trust in their technology.

RELATED WORK

Search and rescue robots are diverse

SAR robots must be able to navigate unconstrained, inhospitable environments [15]. They must be accompanied

by an equally robust distributed computing system that can cope with remote locations and long days [16], [17]. There have been many efforts to address these challenges through robots that assist with different SAR tasks [18], [7], [19], like UAVs for aerial reconnaissance [20], [21], [22], UGVs and snake-like robots for searching confined spaces [23], [7], and robots to assist search subjects [24]. The robots developed for SAR are intended to interact with human teams in disparate ways, from single robot systems [25], [26] to multi-robot teams [27], [17] or heterogeneous sets of UXVs that might each collaborate with a specific human [18], [6], [28]. SAR robots vary with respect to morphology, capabilities, and the ways they interface with humans (or dogs [16]). The broad solution space of SAR robots reflects the varied environments in which SAR technology must be successful. However, solving technological problems around a robot's perception and navigation during a search mission is only half the battle.

Human factors are essential to missions

Human factors like SA and trust are critical for both human safety and mission success [29], [30]. During a search mission, SA demands are inherently high. Teams rely on their shared mental model of a situation to coordinate effectively and use robots [31], and communication is highly structured, often involving searchers on the ground and operations leading from a different location [32].

When robots are introduced, the way that tasks like action generation, selection, and implementation are distributed and overseen directly impacts team's performance [33], [34]. Technologists must therefore choose which aspects of a search task to automate without risking human safety [35], [25], and must design visualizations and interfaces to support these cognitive processes [26], [36], [37].

In wilderness environments, many of these dynamics are exacerbated. Wilderness teams must spread out over vast distances and face extreme conditions—such as avalanches and lightning storms [1]. Communication is often sparse and asynchronous, limited by the lack of cell service and by natural features that block radio signal [38]. As a result, strategies to prioritize information and communicate urgency are essential for the SA of wilderness searchers [3], [39].

Social and sociotechnical perspectives

As Kruijff et al. [23] explains, SAR robots "are all for naught if the humans on the team do not accept a robot's autonomous capabilities." By considering the broader sociotechnical dimensions of robot deployment context, researchers can better understand potential in-the-wild barriers to a robot's success. Qualitative research about SAR has been conducted in several fields [40], [2], [10], including HCI [41], [38] and design [42]. This work has emphasized core features of missions, such as formal division of labor, cooperative planning among human teams, and fast adaptation to situational uncertainty [41], [43]. It has also emphasized how human searchers must contend with the intense emotions at play during search activities and quickly form effective bonds with other people involved [40]. In this work, we perform a similar qualitative examination of robots for wilderness SAR, to better understand wilderness searchers' needs and experiences and the barriers to the success of future technology for wilderness SAR.

METHODS

To understand how robots can be acceptable, trustworthy, and successful given the sociotechnical context of wilderness SAR, we conducted semi-structured ethics board approved interviews with wilderness SAR team members who handle search dogs during missions. Our interviews centered how wilderness teams function, how they collaborate with their search dogs, how training experiences, financial feasibility, conflict, and other experiences may intersect with future technology, and how these domain experts see the future of technology in their field.

We identified potential participants through the websites of local search teams and dog training organizations and recruited three interviewees: Paul, David, and William (names changed for anonymity). Each participant consented to be recorded and was compensated $30. We conducted our semi-structured interviews using Zoom or over the phone. After each interview, we transcribed the recording in Dovetail. Transcripts were anonymized to remove names of specific people or places. We then conducted a grounded theory analysis of the interview transcripts.

INTERVIEW RESULTS

The organizational structure of wilderness search & rescue

Understanding how robots can be incorporated into wilderness SAR requires understanding how search teams function without robots. These team procedures and interactions can be intense when lives may be on the line—recall the story of David's first search mission from the beginning of this paper. The organizational structure of a wilderness search mission is a key example of the broad, contextual factors that new technology must harmonize with to be successful. The set of organizational structures and procedures used by teams starts with the overall division of authority between searchers and operations, including how teams handle decision making and the financial realities they face. Similarly, ground searchers and search dogs face parallel challenges about how to divide decision making and whether or when to initiate a disagreement with operations.

Team structure during a search mission: SAR is often characterized by a structured division of tasks and authority amongst a team [40]. In our geographic area, all wilderness search efforts are specifically led by a county Sheriff's office. Officers from the Sheriff's department maintain a central base of operations during search missions. Ground searchers, dog handlers, or drone operators from local teams collaborate with operations to form and revise the mission plan. Critically, searchers and operations are often strangers to each other. Yet when a mission plan is formed or revised, these mutual strangers must negotiate with each other to form a plan with life-or-death consequences.

The result of this negotiation process is highly dependent on the individual people involved. David explained that *"The Sheriffs are in charge of all SAR staff. They have the option of turning it over to SAR to run the whole thing, or they can run it themselves. And it kind of depends on the, for lack of a better word, the ego of the person in charge as to how much control they're willing to give up."* Paul echoed a similar sentiment regarding his team: *"Sheriffs in this, they don't understand how it works. And they're like, 'just go, go out there and do it' and so we try to educate them, but sometimes they don't really care."*

Relations between operations and teams also depend on the team's reputation. There are several teams in our geographic area that operate relatively independently. Each team maintains its own organizational leadership, training procedures, and certification requirements for both humans and dogs. Though there are local non-profit organizations [44], [45] that coordinate training and certification efforts, there is no universal standard that must be met before a human/dog team can operate in the field. This can cause tension between teams and operations, since the team's reputation is a variable factor. Paul explains that *"It takes many, many years to get yourself and a dog certified. And as far as I'm aware, we have the highest training certifications of anyone in the state. And so people trust us, but there's a lot of teams that have very low certification requirements."* Paul goes on to say that *"so, things like that can also get a bad rep with a Sheriff's deputy that went out with a low qualified team."* William added that this tension also exists between teams, saying *"There's, you know, 'my testing standards are better than your testing standards' and such."*

Search teams rely on volunteer time and money: Because wilderness search teams operate independently, they have unique financial circumstances and often rely on volunteers. For instance, none of the people we reached out to for our interviews are dog handlers as their primary career nor make their primary income from their involvement with wilderness SAR. All three interviewee's teams rely volunteer time and money to operate. When William shared about a recent training exercise, he mentioned that *"It was really impressive with the technology implemented on that day... I mean, that, that one day was like 3 to 4 million worth of assets on the ground or in the air. And I was like, holy smokes, it's a lot of volunteer dollars."* The fact that search teams are independent nonprofits means that their individual relationships with operations and financial circumstances contribute to the team dynamics at play during a mission.

Individual human/dog teams also face complex dynamics: These team dynamics are reflected in the decisions that search team members make. Searcher/dog pairs must constantly negotiate for control. All three interviewees discussed these dynamics. When do search dogs guide team decisions? When do humans take back control? When should humans initiate a disagreement or propose a change of plans to operations? Overall, good handlers give their dogs as much agency as possible, *unless or until* something happens that the dog doesn't understand. David reflected that *"The dog has a lot of control because you know, that's why we have them, to do things that we can't do."* Similarly, Paul explained that *" The dog is doing everything, the handlers, just at the end of the rope, following the dog and and hopefully are interpreting as best they can what the dog is telling them."* During missions, it is the handler's responsibility to keep track of environmental conditions, safety concerns, and team-level planning that the dog isn't aware of. When these factors are salient, handlers intervene. William emphasized that *"There's variables that maybe the canine wouldn't understand, right?"* Handlers assume control when these variables arise. Paul also says, *"so there are some things that the handler's doing that the dog doesn't know. I mean, we're trying to think what time that the person was here. Has it been too long or too dry? Is it rained?... They're interpreting all that, deciding where to take the dog, where the dog would most likely pick that person's scent out."* Handlers also must keep track of safety hazards and the other components of the search team. William explained that *"There are some examples of when (handlers) would take over. Hazards, or other things like helicopters, lightning, drones, or other dogs in the area. You have to work with all the people in the search efforts."* Humans and dogs dynamically negotiate who is in control of decision-making during a mission. When conditions are well-suited for the dog's abilities, handlers follow their lead. However, humans are ready to intervene as soon as something occurs outside of this scope. Such factors can include changes in team-level planning and environmental hazards.

Key Takeaway: Team dynamics are a critical context for roboticists: The organizational and procedural realities underlying missions present critical context for robot designers aiming to integrate robots into real-world missions. During wilderness search missions, teams use a structured division of authority that may not correspond with knowledge or expertise, in which many many parties involved have paid their own way to help find a lost person. Individual searchers working in this team context must make judgements about when to give and take decision-making control from their dog and when to propose plan changes to operations. Ultimately, these contextual dynamics demonstrate the need for effective human factors engineering in this space. Searchers pay for their own gas, at night, to negotiate life-or-death decisions with strangers at risk to their own safety and their dog's safety. If searchers are to adopt a robot into this already complicated setting, then the robot must not interfere with their ability to communicate and stay aware of the search. It must be trustworthy and transparent: supporting users' ability to understand its capabilities and limitations in such unconstrained, hazardous scenarios. The next two sections will further consider specific ways that this complex team context impacts the key human factors of SA and trust.

Trust and certainty come from background knowledge and hands-on training

All interviewees shared visceral stories about learning to trust their dogs. Handlers' trust in their dogs is often

the limiting factor in effective search missions, leading to interpretation errors. To build trust and avoid errors, handlers undergo high-fidelity training exercises, and build scientifically-informed mental models of why their dog is a good search tool and where its limitations lie. When handlers understand the scope of these capabilities and limitations, they can make mission-critical choices about whether to be certain or uncertain about a potential change of plan.

Hands-on training builds trust: All three interviewees stressed that many problems are caused by handlers (especially novice handlers) over-thinking and second-guessing their skilled dogs. David explained that *"the hardest thing for people to do is realize that the dog has all talents necessary. It's the handler that has to number one, trust the dog. And number two, realize that if they knew where the subject was, they wouldn't need the dog. And so we tend to overthink things and we tend to second guess the dog."* Similarly, Paul emphasized *"nine out of ten times, we make a mistake and we don't find someone, it's because we didn't trust our dog and the dog knows exactly what's going on. It's whether the handler is interpreting what the dog is saying correctly."* David mentioned that handlers' personalities affect trust-building, saying *"the handler has to be somewhat humbled by the dog, be able to accept that and work with it."*

Search teams design training exercises to help new handlers build trust and avoid these interpretation errors. Specifically, interviewees emphasized the value of iterative training and double-blind tests. *Double blinds*, as William calls them, are controlled search tasks where neither the handler-in-training nor the tester know the subject's location. William explains that *"I think one of the ways you really build trust is when you have something a little bit more testable. We did a mock mission last weekend about a downed helicopter. And I don't know where the subject is. Nobody in my group knows... that's when you really see the trust. So blind and double blind problems are critical for teams. If you don't have experience with that, you really don't know what it's like to go on a search because you know, that's, that's the ultimate test."* Double blinds provide handlers the opportunity to build trust through active experiences in a real environment. Handlers' trust in their dogs as search tools is critical to mission success. Through active double blind training, handlers grow more comfortable trusting and correctly interpreting their dog's signals during a mission.

Scientific background knowledge builds trust: An outcome of this training process is that searchers build scientific background knowledge, which helps them cement trust in their dogs and advocate on their dogs' behalf to operations. All three interviewees emphasized how knowing the relevant biology and chemistry is part of being a good dog handler. William explained that *"I think the thing that builds trust is, well, I think understanding the science... so having that relationship and understanding"*. Paul also enthusiastically explained the anatomy and chemistry that helps dogs trail scents so well: *"There's bacteria on the skin that are eating those skin cells, and those bacteria are putting gas off and it's the gas that we believe is what the dogs use to identify and differentiate between people."* Scientific background knowledge helps handlers build an accurate mental model of their dog's capabilities—an idea that came up often in interviews. Scientific understanding ultimately helps humans avoid interpretation error by minimizing the times they second-guess themselves.

Scientific background knowledge guides certainty and uncertainty: Accurate mental models of dogs' capabilities, which helped handlers build long-term trust, also matter for in-the-moment decisions about certainty and uncertainty. All three interviewees expressed that having an accurate understanding of their dog's strengths and weaknesses helped them advocate for their own decision-making to operations. Often, this involved understanding the environmental factors that affect their dog's performance. When William first began handling search dogs, he realized that *"right in the beginning, I didn't understand what the dog could do, where their strengths were, where the handler and the dog needed to work together instead."* Now, William says that *"a big piece of it is knowing what (the dog's) details are: when they're doing well, when they're not, and things that make them perform better or worse."*

Handlers understand of the relation between environmental conditions and their dog's performance. They know when to be certain or uncertain about their dogs' accuracy. In wilderness settings, this means keeping track of temperature and humidity. Paul explained that *"during the day, like right now, everything's hot and everything is rising up. At night, everything is cool so it's flowing down. And so when things are rising up, it's much harder for me to get my dog in the same path of where the subject is. At night, it's much easier."* When asked if there were times that he did not trust his dog's abilities, David also shared about environmental factors: *"there's times of the day when dogs are just not as successful. In the heat of the summer, when the scent will tend to rise and rise to the point where it's difficult for the dog to follow. Also, when it's very dry. So you get a dry, hot day, it's very difficult for a dog to do its job. They work better when there's more moisture in the air and ground."* During missions, handlers decide how confident they are in their dog's sensory abilities based on their knowledge of environmental factors.

These mental models of certainty play an important role in decision making during missions. Not only does this understanding build on the existing trust within the handler-dog relationship, it also matters between handlers and operations. Paul shared a story about a search in which he disagreed with operations: *"about 2:00 AM operations calls me up and I said, listen, I'm 98% confident, nearly a hundred percent. I'm 98% confident my dog is trailing the subject and is headed up to the divide, which is 180 degrees opposite of the direction that reporting parties said that she was last seen going. And so 1) command didn't believe me. And 2) they told me because of safety. I tried arguing with them and they were just adamant that I had to return to command immediately."* The subject had indeed traveled up to the continental divide. Unfortunately, the subject passed away

before they could be found. Paul added that communicating with operations in such scenarios is difficult over radio, saying *"it's hard because people don't understand how dogs work and how their noses work. And then we don't always do a great job of describing it, especially over radio, which you have very limited bandwidth and you can't talk, you can't use bandwidth for a long period of time. And so there's often a miscommunication with operations. There's numerous cases where we've been called off when we were definitely following the subject and wanting to find them and then operations didn't believe across the us."*

Key Takeaway: Sociotechnical factors mediate trust: Searchers will need to build and calibrate trust with future robots, just as they do with their dogs. Searchers must build confidence in robot abilities based on situational factors that may change during a mission. This certainty matters for both searcher's decision-making in the field and for team-level decisions with operations. In this way, training and education represent critical contextual factors the success of technology. Training and supporting searchers as they learn to use a new tool, and educating them on its inner workings, capabilities, and limitations, ultimately supports the success of technology in the wild.

The structure of Situation Awareness during a wilderness search mission

A significant portion of our interviews focused on communication and SA within a search mission context. A consistent, structured pattern emerged as to the types of awareness demands searchers face and the communication strategies they use. Some aspects of a mission context call for near-constant awareness and communication from searchers. Critical moments during search demand acute awareness and team communication.

Searchers are constantly aware of a mission's high-level features: Handlers must maintain constant awareness of their physical environment and team plan. Within this, all three interviewees stressed that safety is the primary concern during wilderness searchers. David explained that *"the most important thing is the safety of our dogs, safety of the team members, safety of everybody involved in the operation. When we have the lightening coming in or, or a blizzard, or avalanche danger, anything that is dangerous to the search team and to the individuals is is our prime concern. Everything else is secondary after that."* Paul also reflected that while both urban and wilderness SAR environments are dangerous, they come with vastly different awareness demands: *"in the environment of a building, you know, that potentially is collapsing, they don't want the dog moving around and they also don't want the dog losing the track of where the subject was. The problem with us in mountain SAR is if there's a 30 mile an hour wind and it's snowing out, my dog could be barking 50 feet away from me and I would never hear my dog. I wouldn't even know that the dog had found anyone. So we train differently because of the environments that we search in are so different."* Beyond immediate environmental danger, handlers keep track of their own status and actions with respect to the team plan. William mentioned how *"we're always searchers first. So we have to maintain that while we're also watching our dog and supporting them. So we have to stay together as a team. And then also just being really aware of like, what is your task? So you really kind of have to be, it's called Situational Awareness, being aware of what's going on."*

Because searchers are also responsible for their dogs while in the field, they are constantly watching for communication from their dog and are aware of their dog's status in the moment. These status characteristics include whether the dog is on-scent, off-scent, confused about wind direction, injured, or even over-tired. This means watching a dog's body language. David explained that *"for a trail dog, they get their noses down and their tail is up and they're moving at a certain rate of speed that you can pretty much tell they're on trail... I had a dog, whenever he lost scent, he would just sit down and wait for the wind to change back to the same direction again. And then he would take off. And you know that was difficult to learn, that he knew what he was doing. Sometimes I missed it."* William reported that he communicates about these things with his dog *"almost the whole time, if I can see him. What it look like when he's on a trail, etc. So there's all those things that happen during his work."* This style of communication is learned iteratively during a handler's training. David explained that *"that's always a tough thing to teach a new handler is to watch carefully. We have a new handler that's got a young bloodhound and they were so attuned to find the person that they weren't paying attention (to the dog)."* David also mentioned how this kind of awareness is learned iteratively during the training process: *"trying to get a trainee handler to pay attention to the dogs body language, so that they know whether or not the dog was on trail, was difficult thing."* William emphasized that communication about a dog's general status does not mean that a handler should provide constant *direction* to their dog: *"you don't really need to talk and direct your dog every ten seconds, five seconds, every minute. You can actually say too much."*

Acute search events are rare, but demanding: Besides these high-level characteristics, handler/dog teams need to communicate about sudden events. Ideally, this means that a subject has been located. William explained that *"wilderness dogs usually do a re-find, where they have to communicate to you by going, finding the subject, communicating when they come back to you, 'Hey dad, I found them, we got to go, let's go!' And whatever that communication is. So that's how we communicate and how they communicate with us."* Handlers are also responsible for communicating with operations about how the search team will coordinate. David explained that sometimes *"you've been assigned to search this gully, but your dog wants to go over there into the other person's search area. So do you go, or do you radio to the other team or command? Do you want me to move? You want me to finish searching our area? That kind of thing."* Notably, in wilderness settings, building SA means that handlers must also face uncertainty about whether a

subject has passed away. When he shared the story that appears at the beginning of this paper, David also mentioned how *"that next morning, we were concerned that we were going to be looking for lightning strike victims. Fortunately they made it back okay. And it all turned out well."* Paul explained how this uncertainty leads to different awareness demands and different team procedures compared to non-wilderness environments: *"FEMA has some specific rules. They don't believe that you should ever have a dog that can find a live person and a deceased person because their fear is they're going to be in a collapsed building and the dog will get confused and will alert to a deceased person."*

Communication and Situation Awareness are structured parts of any mission: Building and maintaining SA is a demanding cognitive task that ties together several aspects of a mission context. Awareness demands during a search mission parallel the forms of communication handlers use to confer with their dogs and human team members. Handlers rely on their mental models of certainty to build SA and correctly interpret environmental stimuli. Robots should account for these awareness and communication demands.

What is the future of wilderness search and rescue?

Finally, interviewees shared their thoughts and concerns about the future of SAR technology. Interviewees reflected on the use of drones for search missions and speculated about technology effectiveness and usability. Interviewees had varied attitudes about drone effectiveness. David mentioned that *"(anonymous county) was able to use a drone and actually make a find in a search. And so, because of that experience, they are very open to use of drones where other counties don't have that experience and don't have the trust of the drones."* William shared that his team members were initially skeptical of drones: *"It was like, what the heck? You know, people were pretty skeptical. Some people were all in and other people were like, 'we don't need this drone, we're humans, we got this."'* William clarified that one source of doubt about drone effectiveness was their ability to operate alongside all existing components of a search: *"what to plan for is that dual or overlapping deployment ability. So if you have to shut down helicopters because a drone is flying then you can't put out the fire or you can't get the hurt person."* William added that there is even concern about how drones will affect search dogs: *"I have had people say that we cannot have the drones flying over the dogs because it'll distract the dogs. And I kind of preach the opposite. Your dog should be able to have a drone fly right over him and keep working. Like, that shouldn't be a big deal."*

Interviewees also shared their thoughts on how search teams might react to new robots. Paul supposed operations might trust robots more than handler/dog teams: *"I can guarantee if I had a robot or some kind of electronic device, and I said 'my robot says it has the person and was following them' I don't think they would question it for a second."* Yet he also expressed concern about roboticists over-promising: *"it's okay to have a failure, but don't over-commit to what your technology can do because that's worse than, you know, under committing and underperforming. But if you over-commit and underperform, that's really going to be it. It's the same thing with dogs, you know, they're both tools."*

David was more tentative and supposed that SAR teams would not use robots they were not comfortable with: *"there's a lot of trust because everybody is so concerned about the positive outcome of a mission. They want to make sure that everything contributes to that success. And if they're not comfortable with that particular technology, they may hesitate to use it."* Paul also described how demonstrations of new technologies inspire immediate optimism, but create broken faith when technologies' limitations are revealed. Paul explained *"it's not going to take long for people to gain a lot of trust in [robots]. And that's what happens to me in the drone demos. You see it work and you're like, oh, this works so well. And then you take it out on a search. And, you know, after the fifth time, you're like, I'm never using a drone again, it's a complete waste."* Paul added *"[Robots] gotta be able to demonstrate that it can do things you don't think it can do. And repeatedly, not in a demo, in real world situation. And then I think people will believe in it."*

Paul also thought robots were more likely to be accepted if they were more integrated into the existing team dynamics: *"Let's say that the person running the robot was a member of the team, instead of some stranger. There's going to be a lot more confidence. I think for everyone involved, including the Sheriff's deputies, if it's someone they know in the group previously, versus if it's some computer nerd who walks in. So, that's a scenario that I think would make a huge difference in the trust level."* Interviewees extensively speculated on the future role of robots, sharing their hesitations about robots' ability to operate within heterogeneous teams.

DESIGN GUIDELINES

We now synthesize our findings into high-level design guidelines for human-robot wilderness search teams. Our design guidelines focus on dyadic human-robot teams in wilderness SAR context since this configuration most closely corresponds most with handler/dog teams.

Harmonize with human awareness demands

Robots designed for wilderness SAR must support human SA to avoid over-trust [30] and to mitigate level-of-autonomy trade-offs [46]. For example, a robot that requires human approval to change its current goal is more informative, but costs its operator more cognitive resources. Robots must not compromise their human teammate's awareness of environmental hazards. They should facilitate frequent check-ins about their actions, goals, intentions, and possible malfunctions. Finally, semiautonomous interfaces should have obvious alerts for acute events during a search.

Communicate about uncertainty

Wilderness dog handlers rely on their mental models of their dog's sensory capabilities. By understanding how the environment mediates their dogs' performance, handlers know how confident to be in their dogs. Understanding of

certainty is critical for resilient trust and helps humans feel confident working with their dog in dangerous environments. Searchers need to feel secure in their understanding of a systems capabilities and limitations because they may initiate disagreement with operations based on this understanding. Semiautonomous interfaces for SAR robots can build trust by communicating uncertainty. The ways that robot perception may be affected by environmental factors (like lighting, temperature, smoke, snow, dust, or electrical storms [18]) should be made clear to users. Past work in field analytics has shown that uncertainty visualization affects human decision making in high-stakes, time-constrained domains [17], [47]. Communicating about uncertainty also helps human operators form accurate mental models of robot capabilities and limitations. This matters for long-term trust, team-level decisions, and robot acceptance.

Support dynamic shared autonomy

Our interviews revealed how handler-dog teams dynamically negotiate control. Often, handlers trust dogs to guide decision making *unless or until* something occurs that the dog cannot understand or react to, in which case the handler must override. This dynamic addresses key questions at the core of semiautonomous robotics regarding appropriate levels of automation. While searcher awareness demands will require high autonomy from Wilderness SAR robots, shared autonomy is essential. Searchers must be able to easily override or take control of robots, due to team-planning changes, impending natural hazards, or reports that the subject of a search might be dangerous.

Heed existing training methods

Passive demonstrations of robotic capabilities lead to overtrust and broken faith. Passive technology demonstrations where technology succeeds can spike initial excitement, but quickly lead to disillusionment. In contrast, interactive exercises such as double blind search tasks can foster reasonable expectations and accurate trust. Giving users hands-on experience and time to model system capabilities and limitations is critical to long term success. Moreover, interactive and iterative training can provide searchers with knowledge that bridges the gap between how a system works and when it is trustworthy—ultimately mitigating human error.

Discussion

Are robots the right tools?

While this work aimed to explore the design of wilderness SAR robots, it illustrates the difficulty of creating technology for this domain. Technology must be robust, reliable, and explainable for comparable utility to search dogs. Moreover, many wilderness search teams rely on volunteer time and money, with finite resources. Technology must be compatible with teams' financial concerns, especially because search teams benefit from controlling their own purchasing decisions and training with technology themselves, instead of having it provided by operations [13].

These intense and opposing requirements—that search technology be extremely reliable and explainable, yet also extremely affordable and accessible—ought to encourage researchers to think critically about whether current or near-future robots are the best tool for wilderness search teams.

Limitations

The main limitation of this work is the small number of interviewees, which arose in part due to the limited pool of potential interviewees (Wilderness SAR Dog Handlers in our region). Nevertheless, our three interviewees represent decades of SAR mission and training experience in different regions of our local area across different search teams. It is telling that even three interviews revealed key insights, bringing new awareness of the barriers to robot acceptance regardless of capability. As such, our work nevertheless highlights key avenues for future qualitative research and key considerations for technologists and designers in this space.

Future work

Future work can consider a wider scope of human actors, such as operations, or actors already working with technology—such as drone operators. Future work can also seek to understand mission settings outside of alpine wilderness environments, in which the logistics and hazards of a mission may differ. Wilderness searches are only one kind of search mission; urban, disaster, and other non-alpine wilderness environments each bring their own challenges and team procedures. Finally, future work should explore how our Design Guidelines can be implemented and evaluated. Such future work should focus on not just how to *create* robotic search tools and their user interfaces, but also how to best *introduce* such new technological tools to search teams in a way that fosters calibrated trust and long term acceptance.

Conclusion

Though our set of interviewees was small, their perspectives illustrated the incredible complexities underlying the success of future technology in wilderness SAR. In particular, our discussions highlighted many non-technical aspects of search missions that are crucial for the design of future semi-autonomous wilderness SAR robots. In wilderness missions, strangers come together, using volunteer time and volunteer money, to plan missions, negotiate changes of plan, and make survival decisions. These organizational, financial, logistical, and emotional realities impact the acceptability and trustworthiness of technology, even if that technology performs its technological function well.

While few domains are as intense or complex as wilderness SAR, the need to consider the broader sociotechnical context of technology development and deployment is not unique to this domain. Indiscriminately deployed technology can cause problems, create organizational friction, and build frustration. Exploring such considerations and building relationships with stakeholders during ideation of new technology ultimately supports its success.

One fact stuck with us after our interviews: If you go hiking in Colorado and get lost, the person who rescues you probably paid for their own gas to get there. Researchers developing new technology for wilderness SAR must recognize this commitment by creating technology that is accessible, functional, and that genuinely meets rescuers' needs.

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