Search and Rescue: Dog and Handler Collaboration Through Wearable and Mobile Interfaces

Clint Zeagler
clintzeagler@gatech.edu
Georgia Institute of Technology

Ceara Byrne
ceara.byrne@gatech.edu
Georgia Institute of Technology

Giancarlo Valentin
giancarlo@gatech.edu
Georgia Institute of Technology

Larry Freil
larry.freil@gatech.edu
Georgia Institute of Technology

Eric Kidder
ekidder3@gatech.edu
Georgia Institute of Technology

James Crouch
james.crouch13@gmail.com
Georgia Institute of Technology

Thad Starner
thad@gatech.edu
Georgia Institute of Technology

Melody Moore Jackson
melody@cc.gatech.edu
Georgia Institute of Technology

ABSTRACT

Search and Rescue (SAR) is a critical component of disaster recovery efforts. Every second saved in the search increases the chances of finding survivors and the majority of these teams prefer using canines [5]. Our goal is to help enable SAR dog and handler teams to work together more effectively. Using a semi-structured interviews and guidance from K9-SAR experts as we iterate through designs, we develop a two-part system consisting of a wearable computer interface for working SAR dogs that communicates with their handler via a mobile application. Additionally, we discuss the system around a heuristic framework that includes dogs as active participants. Finally, we show the viability of our tool by evaluating it with feedback from three SAR experts.

Author Keywords

Canine Interfaces, Dog to Handler Communication, Search and Rescue System

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Recent research in animal-computer interaction has catalyzed the creation of computer-aided systems that could allow humans and dogs to work together more transparently and effectively while conducting Search and Rescue (SAR) missions. SAR dog teams are critical for locating missing individuals in the wilderness and in the aftermath of natural disasters or mass casualty events. Search and rescue dogs detect human scent in conditions unfavorable to human vision, such as low visibility environments (dark or highly obstructed) and at far distances. Their scent-detection capabilities, their agility at speeds greater than their human counterparts, and their ability to hear at higher ranges, help increase the efficiency and success rate of non-canine SAR teams.

Although all dogs have superior olfaction compared to humans, well-trained dog-handler pairs are essential for success due to the strategy required for each search. SAR is currently a highly manual job and a single person typically works the dogs on foot. Our focus in this work is dedicated to studying systems aimed at improving this interaction.

Technology such as GPS tracking units [6, 24, 25] are used by handlers and command centers, called 'incident command,' to track dogs in the field. This is especially helpful when the SAR dog leaves the handler's line of sight. Bozkurt et al also describe a wearable computing system for SAR dogs to monitor the dog and the environment, where the dog could even be followed by drones [2]. This could be a very effective way at keeping SAR dogs safe while working. These systems and ones like them are focused on giving the handler more information about the dog's location and wellbeing, but does not allow for the dog to send more information back to the handler. The system we propose in this paper tackles this problem, giving the trained SAR dog the ability to send a message saying, "I've found something important" or "Please come and investigate this." This type of interaction and ability augments the current SAR model, possibly making it more transparent, efficient, and effective.

ACI '16, November 16-17, 2016, Milton Keynes, United Kingdom © 2016 ACM. ISBN 978-1-4503-4758-7/16/11…$15.00

DOI: http://dx.doi.org/10.1145/2995257.2995390

SEARCH AND RESCUE DOMAIN

Search and rescue is an activity defined as "the search for people who are in distress or imminent danger" although in some cases, cadaver searches are also grouped within this category [5]. Although specific definitions vary by jurisdiction, the general field of search and rescue includes many specialty areas typically characterized by the type of terrain over which the search is conducted. These areas include:

- Mountain/wilderness rescue
- Ground search and rescue

- Urban search and rescue in cities (USAR)
- Combat search and rescue on the battlefield

To establish user needs and to get feedback on our proposed SAR system we held semi-structured interviews with nine professional volunteer SAR handlers.

SAR Task Analysis

Task Environment

Disaster dogs are used to locate victims of catastrophic or mass-casualty events (e.g., earthquakes, landslides, building collapses, aviation incidents). Although SAR dogs can be used in urban environments, such as large, controlled settings (hospitals, factories, and airports) we will focus on SAR dogs that work outdoors. In addition to rescue and recovery, outdoor SAR dogs can also perform wilderness, disaster, cadaver, avalanche, and drowning searches [1]. In wilderness SAR applications, air-scenting dogs can be deployed to high-probability areas. These are places where the subject or target have the potential to be, or places where the subject's scent may collect, or "pool", such as in drainage canals in the early morning. Tracking/trailing dogs can be deployed from the subject's last known point (LKP) or the site of a discovered clue [3]. Handlers must be capable of bush navigation, wilderness survival techniques, and must be self-sufficient. The dogs must be capable of working for 4–8 hours without distraction (e.g., by wildlife). Disaster dogs rely primarily on air scent, and may be limited in mass-casualty events by their inability to differentiate between survivors and recently deceased victims.

In the state of Georgia, our expert contacts have stated that most searches occur outdoors and the majority of dogs are exclusively trained for wilderness searches. Since Georgia doesn't have a location for specifically training urban disaster dogs, most volunteers in the state strictly search wilderness. Even when working in the wilderness, it is sometimes necessary to rule out a site without buildings. Examples include ensuring a lost child isn't hiding inside a house, scanning a college campus for a specific person, or checking barns and shelters when searching for someone who may be lost outdoors seeking shelter. However, more commonly, SAR teams look for hunters or hikers who are lost in an area away from any structures. The probabilities of indoor or outdoor work varies significantly by area and is difficult to estimate without further research. For training purposes, our expert consultants practice searching buildings about 15-25% of the time.

Weather

Weather is an important factor that influences scent travel. Scent molecules are typically denser than air, but less dense than water. As a result, temperature can result in "lifting and dropping" the scent, leaving "pools", and the humidity can "bog down" scents. These phenomena can be studied using smoke to see the impact of air flow (indoors and out) and effects of temperatures on the terrain.

Generally, dogs are called out right before the weather conditions are expected to deteriorate. This is because the human search parties refuse to continue at this point and calling the dogs is the last and only alternative.

Wind

The direction of the wind is also an important factor in determining search plans. Teams typically start searches downwind and "grid" across the wind to allow dogs to perceive the scent as it's blowing. If a complete search is performed upwind from a victim, teams are likely to end up going past the victim and then having to backtrack when the dogs detect the scent downwind. Dogs detect which nostril perceives the most scent and use this to determine which way the scent is traveling towards them. Nevertheless, winds in the southeastern United States change directions frequently, so teams must take this into account.

SAR Task Scenario Without Technology

An active search and rescue could have many different outcomes depending on many different variables. We have produced a complete task map too detailed to be outlined here [20], however, we will present a typical search and rescue scenario.

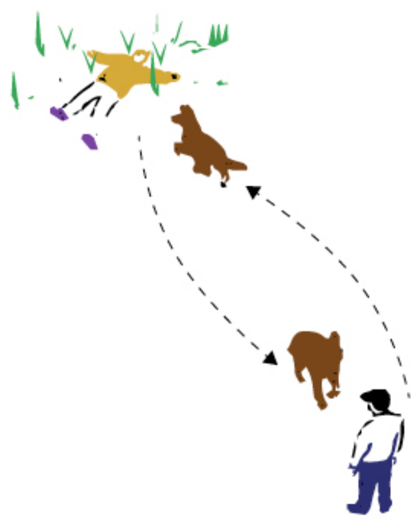

Figure 1: A SAR dog leaves his handler's sight and returns to alert he has found someone, "ping-ponging" back and forth.

Brady is a SAR volunteer; he has a dog, Fancy, who is trained on air-scent searching. The local police department calls for Brady's help when a child goes missing from a nearby playground. When Brady arrives at the playground he is given a map with an area the police would like for him to search. The police give Brady a teddy bear owned by the child so that Fancy can smell the child's unique scent. Brady checks the wind direction, gets out his compass, and sets off with Fancy to search the nearby woods starting from a downwind location. Fancy runs out of Brady's line of sight and Brady hears barking in the distance, which Fancy's alert that she has found someone. Fancy

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returns to Brady and barks to confirm she has found the search subject. Brady follows her, but when they arrive at the location no one is there. This happens quite often when searching for a child, and Brady knows that some children are afraid of dogs and continue to run. After Fancy has ping-ponged back and forth between Brady and the child, Brady finally sees the child and calms him enough to bring him back to the playground and his parents.
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Current SAR Workspace

It is important to understand how a larger working system will operate before designing a new piece of technology. Insights from our expert SAR volunteers guided our participatory design approach..

Interview Participants: K9-SAR Experts

We interviewed nine K9-SAR experts ranging in SAR experience and expertise. Our participants are part of a larger organization that handles incoming SAR calls in the Metro-Atlanta area and reaches out to the individuals with the relevant experience necessary.

Characteristics of Users

Through interviews with our SAR experts we established a set of basic characteristics of the community of users we are targeting. From this, we gathered that there are both male and female users. The user population has a very diverse age range, from young enthusiasts (older than 16 years) to agile senior volunteers with their trained SAR dogs. For this reason, it is important to keep the system informative, but flexible for the very broad range of people who would use the system.

One common attribute is that all of the people volunteering in an SAR operation have to be certified in SAR through programs such as the National Association for Search and Rescue (NASAR) or the North American Police Work Dog Association (NAPWDA) and many have held or continue to hold occupations useful for on-site crises – many are Registered Nurses, Firefighters, or Paramedics. They gain valuable information during the SAR training process, but it also gives the administrator an opportunity to fully explain a new SAR Handler Application. We can expect all of our users to be able to read in English, and understand a geophysical map. We can also expect all of our users to be physically capable of performing the task of searching outdoors for extended periods of time.

Social

The current social context of Search and Rescue specialists is heavily influenced by interactions with first responders. In most jurisdictions in the United States, local police officers or park rangers conduct the first attempt at SAR. Once this approach has failed, or the human parties are unable to continue a search, the Search and Rescue teams are contacted for support. In some situations and jurisdictions, it may take hours or days before the teams are contacted. As such, Search and Rescue teams believe that their work would benefit from closer collaboration with local authorities.

Current Technology Use

The current use of technical systems, such as GPS, to assist in search and rescue varies greatly with each team. Most SAR teams are comprised of voluntary members and technology is not provided by the organizations they belong to. SAR teams that receive technology grants typically obtain GPS receivers and handheld radio equipment in addition to smartphones. The radio equipment and phones are used to communicate with other teams in the near vicinity to coordinate their efforts. Teams that cannot or prefer not to use computing technology rely on paper maps and compasses.

Our group of SAR experts also uses the TNP Terrain Navigator Pro [21] to help mark areas they have searched and to produce reports they are required to provide to law enforcement once the search is complete. They use One Call Now to call out to their SAR volunteer phone tree. The also keep an e-copy of Lost Person Behavior [14] on their mobile devices for reference as they search. Other useful mobile applications they listed were:

- Koredoko - provides the GPS coordinates from a picture taken on a cell phone. If a person is lost, but has a cellphone, they take a picture and text it to law enforcement. The image is opened with Koredoko and it opens a Google map with the location of where the photo was taken, with latitude and longitude coordinates, along with additional useful information.
- Map Tools: coordinate system conversion between latitude/longitude, Universal Transverse Mercator, and National Geodetic Survey coordinates.
- Microsoft OneNote: note-taking and freehand drawing
- Evernote: note taking, photo integration into a document
- Google maps: location identification and directions to a search area, looking at past satellite views of an area

In our discussions before, we broached the topic of canine / human technology mediated collaboration, many of the SAR experts wanted to focus on methods to ease their workflow through a SAR system combining their existing tools. They wanted to include their Pack check list as well, which is a checklist they use in packing their equipment before they leave for a search. They described how helpful it would be for this system to pre-fill a majority of the information on the Incident Command System (ICS) Form [10], which is a form that the SAR team has to fill out to give law enforcement after their search. Much of the needed information to fill out the ICS Form is capable of being collected by mobile devices while in use.

On the canine side, common devices include a padded stick known as a *bringsel* [9]. This stick is attached to the collar of an SAR dog in a manner that allows it to swing freely. When the target is found, the dog bites the bringsel and holds it in his mouth until returning to the handler. In this way, the dog effectively communicates the completion of a successful search.

USABILITY CRITERIA

The following ten usability criteria were isolated from work by Nielsen [18]. In addition, we have provided an interpretation of how we might implement these criteria to a proposed digital SAR dog and handler communication system, based upon information gathered from our SAR literature review and expert SAR handler interviews.

1) *Visibility of system status*: Handlers should be aware of their dog's location(s) at all times; similarly, the system should be able to provide the dog with appropriate feedback at the appropriate moments.

2) *Match between system and the real world*: Cardinal directions should be maintained by connecting generated maps with compasses. The system should provide affordances appropriate for dogs. Information to the canine and handler should be natural and in a logical order.

3) *Users control and freedom*: Our system should support the ability to navigate menus quickly by incorporating undo and redo buttons on every interface. It should also interact well with other applications since users will need to swap between different systems (e.g., radio) rapidly.

4) *Consistency and standards*: Our design should follow Gestalt psychology principles, mimicking popular current analogies such as Google Maps/GPS, and leverage existing SAR standards.

5) *Error prevention*: Because many decisions must be made with haste and while in motion, the transparency of actions, such as clicking 'yes' or 'no', is important and providing confirmation of actions, for instance, "Are you sure?" helps manage errors.

6) *Recognition rather than recall*: The system should minimize the human and canine's memory load by making relevant objects, actions, and options visible.

7) *Flexibility and efficiency of use*: The interface should allow for both experienced and inexperienced users by handling "accelerators" or tools that can speed up interactions.

8) *Aesthetic and minimalist design*: Screens should not be cluttered with obtrusive or unnecessary information and should maximize the screen utilization for relevant information, such as maps. Since speed plays a pivotal role in SAR missions, graphical quality should be sacrificed in favor of functionality. However, decreased accuracy is the trade-off.

9) *Help users recognize, design, and recover from errors*: User interfaces should be sufficiently detailed such that users do not get caught in endless loops that are costly to efficiency and success.

10) *Help and documentation*: Whenever the application fails or if the user needs assistance, access to external resources (e.g., emergency phone numbers) should be presented.

RELATED WORK IN CANINE COMPUTER INTERACTION

There is a quite a bit of current work surrounding animal-computer interaction [15–17], specifically working dogs and their interaction with technology. Robinson and Mancini describe a domestic system where trained assistance dogs interact with mounted pull tabs and other sensors to call for help in case of a home emergency [19]. Zeagler et al's motivation for studying a dog's ability to interact with an IR touchscreen is quite similar. They were also interested in understanding how to better create Touchscreen systems for canine interaction [26]. Within the domain of SAR dogs, Ferworn et al augmented dogs with video capture for monitoring while searching areas unsafe for humans [7, 8], and Tran also works to collect information from the environment around the SAR dog [22]. In any case, assistance dogs are being trained to effectively interact with technology to support the dog's working life. On-dog-body interfaces for dogs to use while wearing their service vest, designed by Jackson et al, have been tested and found to be quite effective [11]. One such sensor, the capacitive bite sensor [12], was chosen to use as our dog interface for communicating to the human handler.

SYSTEM DESIGN: OUR SAR DOG VEST

The working SAR, wearable computer communication dog vest components include a Capacitive Bite sensor [12] (figure 4) in order to detect when the dog bites. Additionally, a central hub with Bluetooth Radio is used to broadcast sensor activation feedback tones to the dog and activate alerts to the cellular phone. The cellular phone tracks the precise GPS location of the dog, and send the alerts from the Capacitive Bite sensor to the backend server API. The components are sealed in an OtterBox™ protective case to protect the electronics from water (figure 5). Furthermore, the cell phone is an S4 Active, which is designed to be water resistant.

The vest also has an additional capacitive sensor chest strap, which was designed to prevent false-positives if and when the dog traveled through water. Since the dog would not intentionally activate the chest strap, it works to detect if the dog is in water, thereby deactivating the side-mounted capacitive sensor used for alerts. Shortly after the dog has left the water, the chest strap deactivates and re-enables the alert sensor.

The construction of the vest and the materials chosen reflect the type of activity, the wearer, and the environment. A Julius K9 powerharness [13] is augmented with extra foam padding to stabilize the vest while in use and to take pressure off the dogs spine (figure 6). The location of the on-body dog interaction was informed by previous research in canine reachability of snout-based wearable inputs [23].

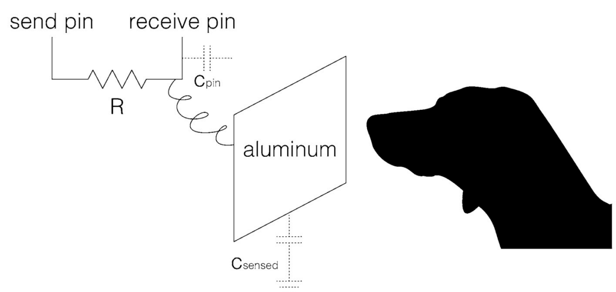

Figure 3: Capacitive sensor operation[12]

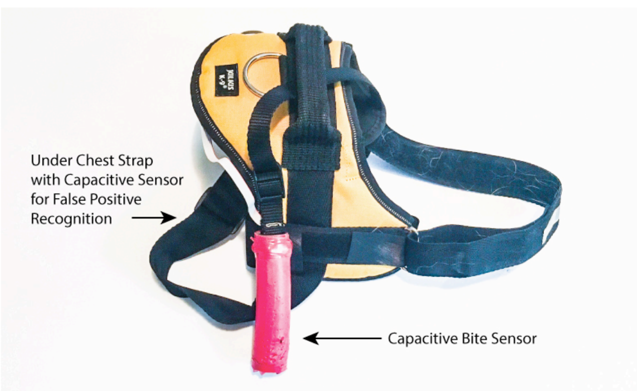

Figure 4: SAR working wearable computer vest

Figure 5: SAR working wearable computer vest

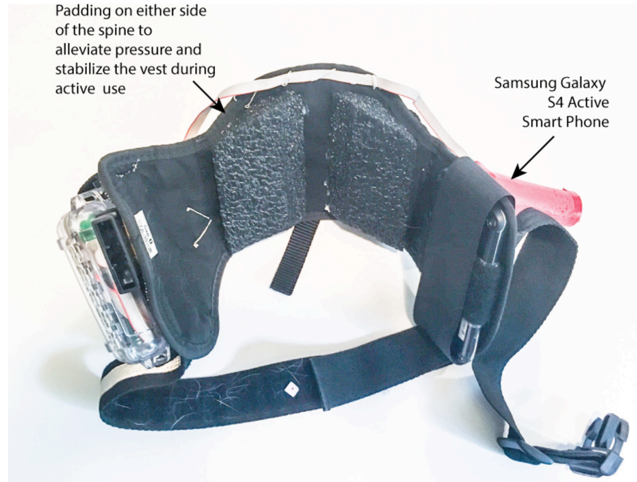

Figure 6: SAR working wearable computer vest

Dog Activation

During a typical SAR scenario, the working dog is trained to alert the handler that he has found something of interest. In this case, the dog would bite the capacitive sensor at his side (Figure 7). Notice the bite sensor is the same shape and size of a bringsel, which follows our second heuristic *Match between system and the real world.* Upon activation, the dog's system beeps a tone, notifying the dog that he has made a successful activation (the dog is trained to understand this tone as a reward marker, and as the completion of a task). Also upon activation, the dog's vest would send a signal through the cell phone to the handler's smart phone, including the GPS data and activation information.

Figure 7: Border collie activating a capacitive sensor [12]

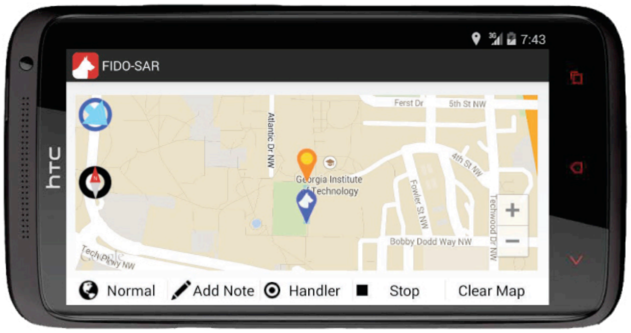

Figure 8: SAR Handler Interface showing dog location, handler location, wind direction and compass.

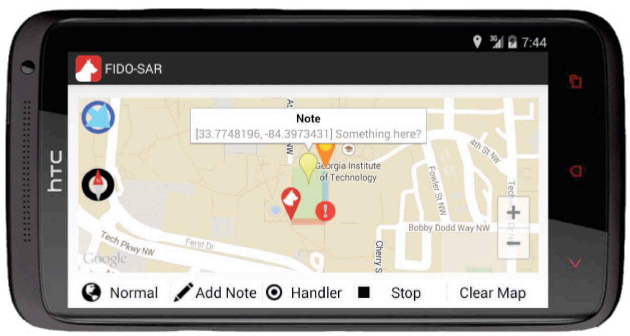

Figure 9: SAR Handler Interface showing a dog activation, and also a note entered by the handler.

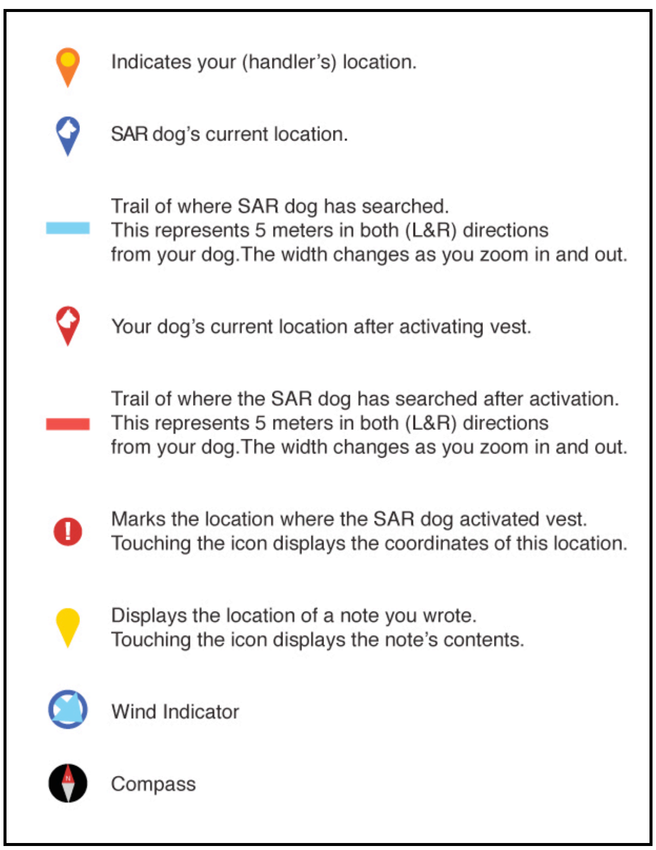

Figure 10: Handler Interface icons and meanings

SYSTEM DESIGN: MOBILE HUMAN INTERFACE

The human interface for monitoring the dog's location and activities is an application that runs on an Android platform. The application works on all GPS-enabled Android cell phones and tablets, but currently requires a device that can pick up cellular service while in the field. The SAR handler application (Figure 8 & 9) shows the location of the dog with respect to the handler's location on a map. The application also shows a compass and general wind direction, as gathered from local weather data. What differs about the program from other GPS tracking systems is the ability of the system to mark searched locations and receive input from the SAR dog.

As the SAR dog moves, a path is drawn on the map showing where the dog has searched (Figure 9). The path is set to a width advised by our SAR experts. After we inquired the distance from the dog the experts would feel comfortable saying the dog had searched, the width of the path search was set to a total of 10 meters wide. This distance from the dog is also a conservative translation of an air-scent trained SAR dog's ability when working in hilly forested terrain. If an SAR dog finds something he believes he is looking for, he will be trained to activate his capacitive bite sensor. Upon activation, the handler application will mark the point of activation and continue to follow the activated dog's path. This allows the dog to continue without returning to the handler (which is helpful in our earlier scenario of a frightened child). The path is displayed as red until the dog returns to the handler. As the handler follows the dog, the handler can leave GPS-tagged notes on any points of interest or they can document context clues seen by the handler along the path (Figure 9).

The menu buttons along the bottom of the screen (from left to right) allow the map to be toggled through street/satellite/hybrid views, allow the ability to create a note, allow the handler to re-center the map on themselves, allow them to stop the program, and allow them to clear the map. Adding a note, stopping, and clearing the map all have error prevention pop up confirmation screens.

PROTOTYPE TESTING AND ITERATIONS

To test our SAR system, we asked one of the volunteer SAR handlers to train a dog using our vest. We conducted the prototype feasibility test on a 72-acre, fenced property containing fields, paths, and wooded areas. We had one of the members of our team hide, and the SAR volunteer used the vest and dog to search. We were able to follow the dog's path as expected. When the dog activated the system, it responded as designed. As this was a prototype test of the system, our goal was to gain handler feedback, and as such, when found, the team member prompted the dog to activate the sensor. We were not trying to test the dog's capability of using the system at this time, although the dog's ability for sensor activation was tested in a previous study [12]. During the course of the prototype test the handler was able to clearly understand the mobile interface.

The handler also directed the dog to run/swim across a small lake, after which the system again responded as designed. The capacitive chest strap stopped the bite sensor from sending false positive signals, and everything began to work like normal once dry. The more compact version of the SAR vest, as seen in Figures 4-6, is not waterproof, the lake test was performed with an earlier and larger, but waterproof vest with the same capabilities.

The first version tested was quite larger in scale. The OtterBox™ was double in size and the bite sensor was larger and hung lower on the dog's torso. After feedback from the SAR handler we knew we had to make the system more compact for it to be viable. The handler's main concern was the vest catching when the dog had to run through dense brush. The current model is now much smaller and compact, but our goal is to continue to reduce its size.

FEEDBACK FROM SAR HANDLERS

Additionally, to evaluate our system, we shared both the handler and canine interfaces with three expert SAR handlers having extensive experience in dog tracking (approximately 9 years). All three SAR handlers, who shall be referred to as E1, E2, and E3, received the system with positive reviews and provided constructive feedback on how to make the system more robust for fieldwork. In the words of E3, "overall, very impressed with the product."

SAR Dog Vest

While we show through our testing and iterations that the system was effective for canine interactions, E1 and E3 recommended improvements for durability, visibility, and connectivity to the handler.

Durability

In the words of E3, it's incredibly important that "all equipment, cabling, handles, straps, and material must be Georgia-briar-patch-proof, water/humidity-proof, and heat-proof (110+ degrees F), otherwise it won't last a summer." E1 recommended making the vest lighter and more breathable, saying that their canines were not accustomed to working with vests on. While this is not the case for all SAR handlers, the vest should not overheat the canine while they are working.

Furthermore, all three experts were worried about the footprint of the vest and the possibility of it snagging on the brush while their dogs were working. While the Capacitive Bite sensor doesn't need to be tugged, E3 mentioned that "QASM (Quick Attach Surface Mount) connectors should be able to withstand up to 200lbs of pulling force -- I've seen trailing dogs nearly pull an adult male off his feet when starting a search." E3 also recommending building the Styrofoam pads into the vest so that the structure of the vest remains, but that they don't come off while working.

Visibility

E3 requested that the vest be recognized as a working dog vest and, as such, come in colors related to safety work, such as safety orange or green. Additionally, it is important for handlers to be able to put appropriate and easily identifiable Service Dog badging on their vests.

Connectivity

E3 had a few concerns regarding how the vest connected to and relayed information to the handler's device. Our decision to use Bluetooth limits us to approximately 100 feet, and E3 recommended using longer range protocols, such as cellular. Additionally, E3 requested that the SAR dog vest record information locally in the event that connections were not stable so that their paths were still logged, but so that they could be pushed to the handler's device once connectivity was restored.

Mobile Human Interface

The mobile human interface also received positive feedback, however they provided constructive criticism regarding mapping, iconography, and annotation.

Mapping

All the experts highlighted the fact that the mapping functionality was the most important aspect of the handler interface. "Mapping is critical to the search and anything that obscures the minimal space we have on the screen will detract from the benefit of having that screen," said E3. Additionally, terrain maps were preferred over Google's street-optimized view.

Secondly, there were concerns using latitude and longitude as the primary means of displaying coordinates. E3 mentioned "Lat/Long is good, but the US government has standardized on USNG as the preferred coordinate system with WGS84 as the datum for SAR mapping." The additional perk of switching to USNG is that it is a shorter notational method and will therefore reduce screen real estate coverage.

Iconography

The experts were extremely happy with the functionality and readability of the icons. However, as the map is the primary functionality of the handler's device, E3 recommended that we reduce the size of the icons or decrease the opacity when they're not in use.

Annotation

All three experts expressed enthusiasm for the ability to attach notes to specific incidents and GPS coordinates. However, they requested further functionality. In particular, E3 noted that most handlers work with gloves on and that they may not be able to have easy access to typing. The ability to use voice-to-text or attach verbal messages to a location would help facilitate the process.

FUTURE WORK

After building feedback into our system, our next step is to create a user study to determine how well our prototype will work during extensive use in the field. There might also be an opportunity to combine some of Bozkurt's wearable dog and environmental monitoring [2] and remote human to dog communication. By using research from Britt [3], combined with newer data on a dogs ability to feel and understand haptic input [4] we could move towards creating a system where the handler could guide the dog remotely.

SAR Task Scenario With Technology

We present a projected scenario of a SAR team using the SAR system described in this paper.

Brady is a SAR volunteer. He receives an SMS text message to his smart phone asking if he is able to come and search for a child missing from a playground. He responds yes and opens the SAR application on his phone. Driving directions to the playground are already downloaded, as is the search area assigned to him. The application also shows wind direction and has a compass so Brady can decide where to park so that he will be downwind. He loads Fancy in the car and heads to the playground

Upon arriving, he is given a sample of the child's clothes for Fancy to smell. He takes a moment to ask the parents of the child to prerecord a message into Fancy's SAR Vest. He places the SAR wearable computer vest on Fancy (which she takes as a signal that they are now at work) and she heads off ahead. Fancy leaves Brady's line of sight, but he can still follow her and view where she has searched on his smart phone application. As he watches the phone, he is notified that she has lingered in one spot for a while. He walks to that spot and sees a teddy bear left on the ground. Brady picks up the bear and leaves a GPS located note on his SAR app. Brady starts to follow Fancy again and hears a tone notification and feels a vibration from the phone. He looks at the phone and sees that Fancy has activated her capacitive sensor indicating that she thinks she has found the child. Fancy, however, continues to move after activation for 100 yards. When Brady finally catches up with her he can see the child, and also hears the prerecorded message from the parents telling the child that the dog is nice and to stay with her until help arrives.

ACKNOWLEDGEMENTS

We would like to express our gratitude to the National Science Foundation for supporting this work under award IIS-1525937. We would also like to thank Barbara Currier and Gabby Gammans for their help with dog training.

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