Wearable Alert System for Mobility-Assistance Service Dogs

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Abstract

We present a study of a wearable alert system for mobility-assistance dogs. Our focus in this study is on assessing sensor and dog activation reliability for the purpose of understanding both system and dog training challenges. We improve on the results from previous work in each of four performance metrics and we present solutions to some practical issues necessary for achieving more reliable and consistent experimental results. We also interviewed active service dog users concerning technical, social and canine considerations, the results of which may inform future studies.

Keywords

Animal-Computer Interaction, Canine-Human Communication, Wearable Technology, Service Dogs

Introduction

Mobility-assistance service dogs, as defined by assistance dog organizations in the United States, are trained to help users who use a wheelchair with tasks of daily living (Fig. 1). These can include opening a door, picking up dropped item, and pulling a wheelchair. In cases where the human companion has a condition associated with unpredictable episodes or periods of incapacity, such as seizures, the service dog can assist the human to a safe location.

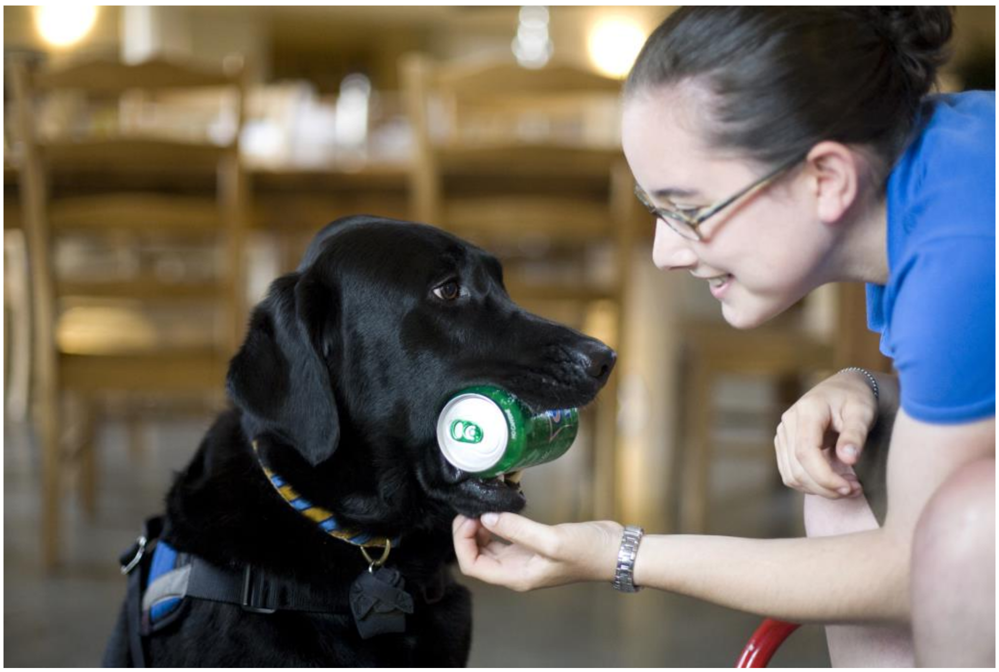

Fig. 1. Mobility assistance service dog. Reprinted with permission from Canine Companions for Independence.

We present a system (Fig. 2) to enable a mobility-assistance service dog to request help for humans who, in the case of an emergency, might be unable to request it for themselves without additional support. In this study, we explore the scenario where the owner instructs the service dog to "get help" from an individual at a fixed distance within line of sight of the dog. In such a scenario, the dog would locate and move towards the targeted individual to activate a wearable sensor that plays a pre-recorded message. In the current prototype, the message says "*My owner needs your attention, please follow me!*"

Fig. 2. Service dog wearing one of the early prototypes. When tugged, the microcontroller on the vest plays a message saying "My owner needs your attention, please follow me!" Reprinted with permission from Canine Companions for Independence.

Related work

The present work is a continuation of an effort to augment communication of working dogs (Jackson et al.,1). Researchers at the Open University created one of the first examples of an alert system for service dogs, aimed at diabetes alert dogs (Robinson et al,1). This system used a tug toy in a static location in the owner's home and would be pulled in case of an emergency. Building on our previous work, we sought to combine approaches using an augmented vest that would allow the owner to call for help in indoors and outdoors environments.

Method

Materials

The main pieces of equipment in the present study were four instrumented dog vests consisting of a tug affordance and the associated electronics to produce an audio message when it was pulled.

The tug affordance consisted of either a 'Kong Wubba' toy (Fig. 3) or an equivalent braided fleece. We connected these affordances to a flexible stretch resistor by Images Scientific, Inc., which acted as a sensor whose resistance changed when stretched (Fig. 4). According to the specifications: "when relaxed the sensor material has a nominal resistance of 1000 ohms per 2.54 cm (1 in). As the sensor is stretched the resistance gradually increases." We connected it in a voltage divider configuration as shown in Fig. 5 using a 10 K ohm resistor. VDD (5 V) and GND can be changed depending on whether one wants the values to increase or decrease when stretched. We selected the former because we deemed it more intuitive to have the sensor values increasing when tugged. The sensor is a "flexible cylindrical cord with hook-terminals at each end. The sensor measures 10.16 cm (4 in) long, not including the electrical terminals, and .1525 cm (0.060 in) in diameter." (Images Scientific, 1)

Fig. 3. Commercial Kong Wubba toy affordance.

Fig. 4. Stretch resistor by Images Scientific. This resistor was used to measure the strength of a pull on the tug affordance.

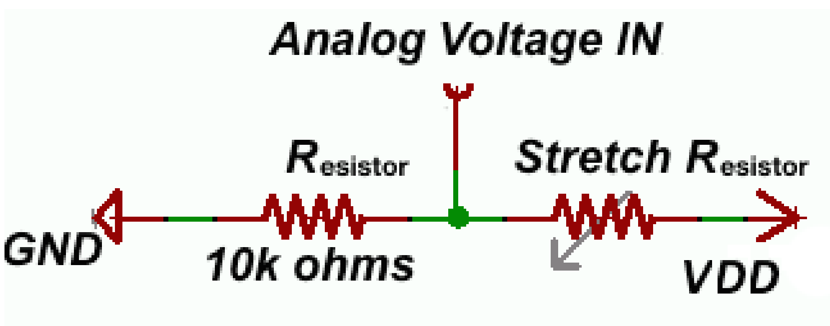

Fig. 5. Voltage-divider schematic. The 3.3V and GND can be interchanged depending on whether one wants the values to increase or decrease when pulled.

The electronics consisted of four elements. The first was the Arduino UNO R3 microcontroller development board based on the ATMEGA328P microprocessor. The second was a companion hardware adapter known as a *Wave shield* manufactured by Adafruit, Inc to store and produce .wav audio files. Because the Arduino is a digital device, the shield modulates the width of different square waves using a technique known as pulse with modulation, PWM, to reproduce the sound necessary to play a given file. The third and fourth components were a speaker and a 9V battery pack, respectively.

Participants

To test this system, we conducted a pilot study with n=3 dogs trained for a particular task. These included an inactive assistance dog, an active medical alert dog, and an allergy detection dog in training. They were males ranging between 6 and 7 years of age (Table 1). We did not train active service dogs on using our prototype vests for the purposes of this experiment to avoid altering their training. However, partners of active service dogs were allowed to informally train the use of the vests at their own discretion and provide any feedback to improve our design.

Table 1. Subject demographics. Crosses between Labrador Retrievers and Golden retrievers are signified LGX and border collies are denotes as BC.

Subject	**S1**	**S2**	**S3**
Breed	LGX	BC	BC
Training	Service (Released)	Nosework (Training)	Medical Alert (Active)
Sex	M	M	M
Age	7	7	6
Weight	31.75 Kg	21.3 kg	15 Kg

Procedure

Each training session lasted at most 30 minutes. Both S2 and S3 had formal experience with the activation sensor from participation in previous studies with similar interfaces. S1 required refresher training because he was previously unable to activate a wearable tug sensor in prior experiments. This type of training required becoming familiarized with the sensor and included interactions ranging from touching it lightly to biting it and finally tugging. Unlike other subjects, S1's inclination is not to play by tugging, so this behavior had to be trained prior to the experiment. For consistency, we placed the activation affordance on the left side of all dogs.

Once video recording began for a given trial, the dog was allowed at least three attempts at tugging the wearable sensor to determine the optimal angle for the affordance. Once we calibrated the angle, we began the testing phase. The dog handler instructed the dog to tug the wearable sensor through the "get it" command and a hand gesture. If the dog was able to activate the sensor, the handler provided a small food reward to the dog. The handler repeated this process for at least ten repetitions.

Prototype 1

When asking service dog partners about using a vest like the first prototype they expressed concern that the visible electronic components could be intimidating to by-standers (Fig. 6). If so, this aspect could limit the vest's functionality because one of its main purposes is to communicate a message to unfamiliar individuals. More importantly, placing the electronic components at the center of the vest made the handle unusable (which could impede the dog from pulling a manual wheelchair). We also noticed that the weight falling on the spine made dogs' posture change when they used it for extended periods of time.

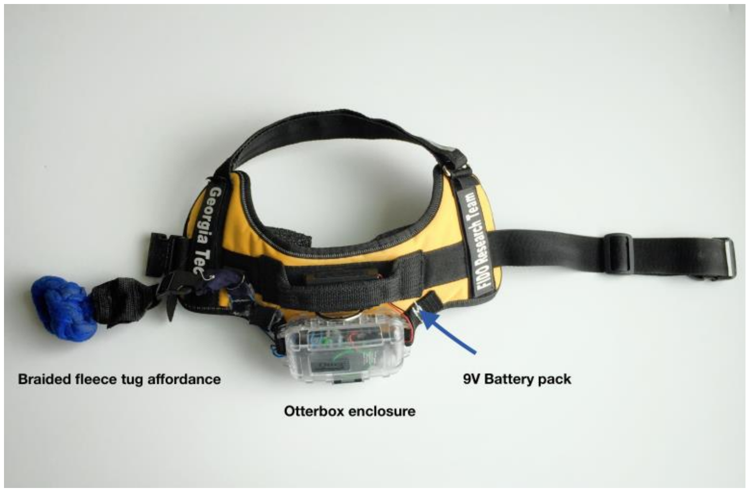

Fig. 6. Prototype 1 used a Julius K9 vest with electronics components mounted on the top.

Prototype 2

The first change we made to address these concerns was to use an opaque enclosure to conceal the microcontroller and the battery. We also routed the wires along the inner seems of the vest to conceal and protect them (Fig. 7). We also moved both the microcontroller and the battery to the right side of the vest to allow access to the handle. With these improvements, the vest no longer appeared menacing to unfamiliar individuals according to anecdotal reports from one user. Unfortunately, the weight of the electronics (right side) was greater than the weight of the tug affordance (left side), which caused unforeseen issues. For example, every time a dog would tug the affordance, the sensor would dangle to a new position. In some cases, this new position was easier to reach, while in others it was more difficult.

Fig. 7. Prototype 2 used an official service dog vest. This design concealed the wires and electronic components to achieve a simpler look. Reprinted with permission from Canine Companions for Independence.

Reachability

At this point, we began to reconsider the side placement altogether. One user suggested that a dog reaching a tug affordance to their side would be as difficult as a human opening their backpack while standing. To verify this, we decided to test the notion of "reachability" independent of any one sensor (Valentin et al, 1). We tested seven locations and each dogs' ability to reach them (Fig. 8).

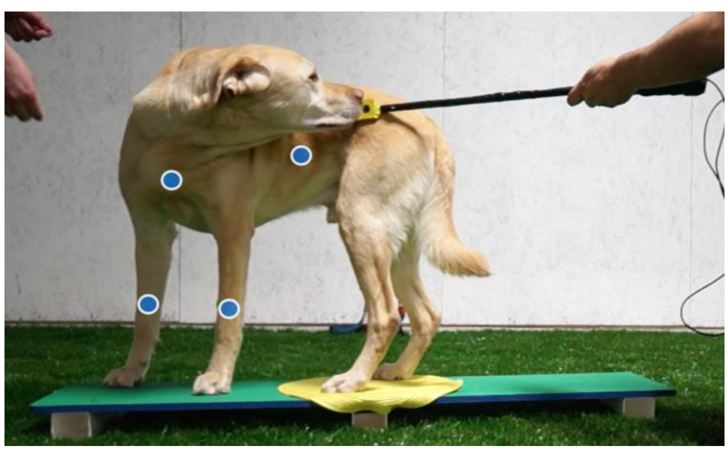

Fig. 8. Seven on-body locations were tested; three locations are illustrated in this image.

We observed that although placements on the sides were at a significant speed disadvantage to those in the visible parts of the chest and neck, this advantage decreased significantly with training (Fig. 9). Nonetheless, even with training, the side locations still exhibited a higher error rate than placements within sight.

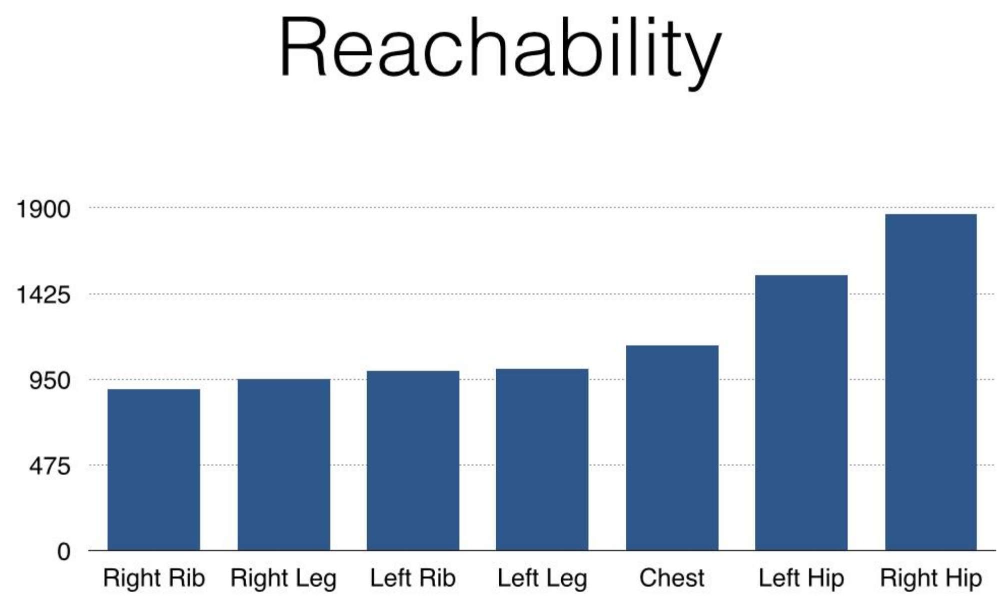

Fig. 9. As seen above, with training, some side placements even achieved faster access times than some front placements.

These findings led us to hypothesize that the main disadvantage of the side placement was the undirected nature of reaching for the ribcage area. Because the dogs did not know where to tug or touch, they had to use a trial and error approach. These insights led us to reconsider the "dangling" nature of our tug sensor because its location was unpredictable. Some dogs got around this issue by raising the tug affordance with their leg or swinging it hard to enough to bounce it against their body and grab it in midair. Both of these activities were extremely energy-intensive and not suitable for long-term use.

The second lesson was that placements on the sides did not necessarily mean equal access for all the dogs. Dogs' anatomy varies more than any other species on earth (Berns, 188); and even within the same breeds, each dog had different sizes and flexibility. We decided that our next prototype should be adjustable for each dog without requiring hardware or software modification.

Prototype 3

Due to the experimental nature of this prototype we reverted to using a Julius K9 dog vest rather than an official service dog harness. We replaced the plastic enclosure (Otter box) with a fabric cover. The fabric cover provided a lighter weight alternative that could be easily attached to the VELCRO strip that is built-into service dog harnesses like the Julius K9 vest. To keep the location of the affordance consistent, we used a fabric tube to keep the sensor in a predictable horizontal position, rather than dangling freely (Fig. 10).

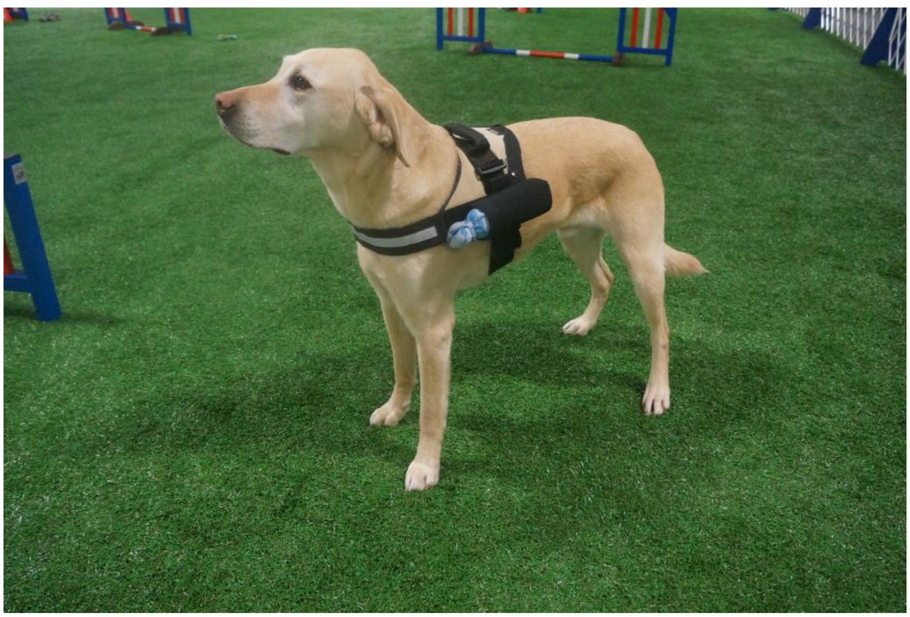

Fig. 10. Prototype 3 being worn by one of the participants. This prototype has a fabric tube that holds the tug affordance in place. The tube can be angled downwards to provide easier reach.

Our testing revealed that the fabric enclosures were helpful in reducing the weight, but they did not allow access to the electronic ports required for turning on the battery and programming the microcontroller. The VELCRO attachment holding the electronics on the side of the vest was not secure enough for vigorous activity. Similarly, the saddlebag-style placement, where the components on each side counterbalanced the ones in the other, was integral for minimizing the shifting of the vest as a whole, which was an issue that increased the difficulty of using the first two prototypes.

The VELCRO-based system, where the tube containing the tug affordance could be repositioned and angled from 0 to 45 degrees allowed for necessary adjustments for each dog. The tube itself was as long as the affordance and tended to make grabbing it difficult. Surprisingly to us, when reaching unsuccessfully for the sensor subject S1 would only manage to nudge the tug sensor and, unwittingly, push it further into the tube rather than outwards.

Prototype 4

We used a larger fabric box secured by metal snaps to store the electronics, rather than VELCRO so that the only VELCRO remaining was the one intrinsic to the Julius vest.

Fig. 11. Prototype 4 used a large fabric box secured with snaps to house the Arduino UNO, its wave shield, and the speaker. We used screw terminals to secure the wires in case the sensor needed to be replaced.

We shortened the tube to expose the entire round portion of the Wubba toy and lined the inside of the tube with industrial grade felt to act as a stopper so the Wubba toy was not pushed in.

Every time the angle of the tug sensor was changed, the baseline resistance would change as well. Due to the 10-bit analog converted, the stretch values were represented as a number from 0 to 1024. Up to this point, we set the threshold at a 50% level or 512 units for activation to be detected and the message to be played. In the current prototype, a single numerical threshold would no longer work. We needed to analyze changes in the last 10 samples and set the threshold accordingly. In this case, we determined a change of 25 units in the span of 10 samples to be a suitable threshold (Fig. 12).

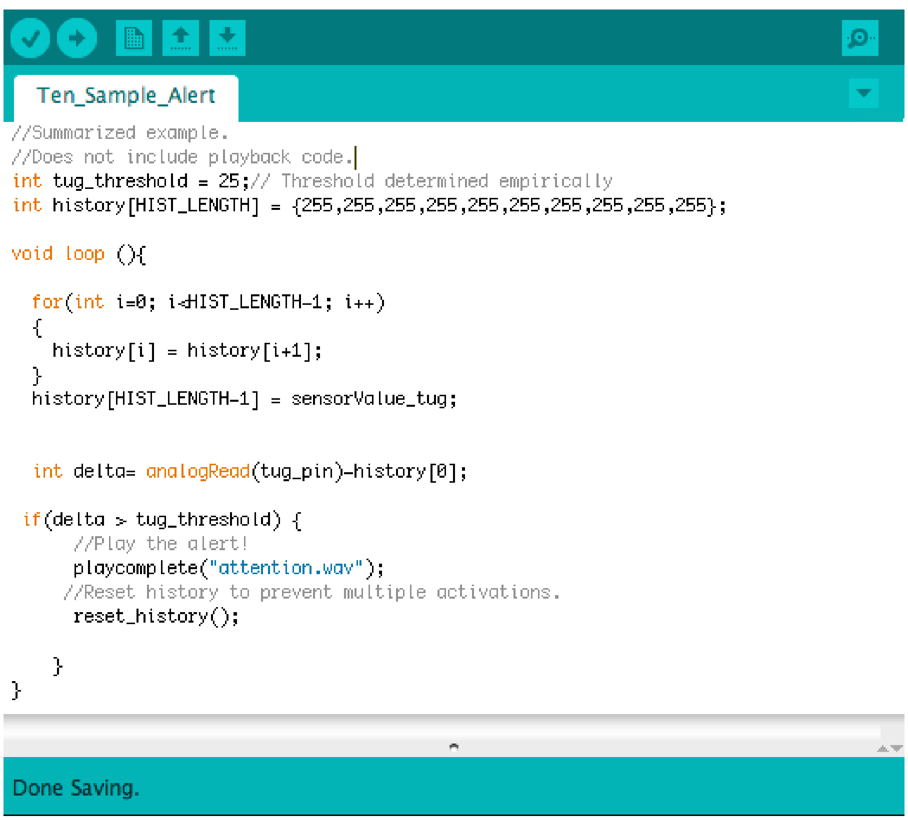

Fig. 12. To account for changes in the orientation of the tug affordance, we determined a change of 25 units in the span of 10 samples to be a suitable threshold.

Discussion

Although such considerations were not necessary for everyday use, some critical changes were made for the benefit of facilitating experiments. First, we created two access ports, with metal grommets, to connect the battery's barrel connector and the USB cable that were required for re-programming the microcontroller. For example, reprogramming might be necessary to adjust the sensitivity threshold of the sensor or adjust the parameters associated with audio playback. Second, a replacement tug affordance was created in case the original one became slippery due to the saliva from repeated activations. This replacement was necessary if more than one dog was to use the vest on a given day (Fig. 13).

Fig. 13. Prototype 4 had two tug affordances. Each affordance consisted of a tug toy whose flaps were cut, sewn together and attached to a plastic clip.

In previous experiments, testing dogs of different sizes required multiple vests to be instrumented. In some cases, this issue resulted in three duplicate vests being created and simultaneously maintained. For example, if our testing showed that a vest design required modifications, these modifications had to be duplicated for each vest size. This limitation made rapid iterations difficult and limited the speed at which we could try new designs. For this study, we devised a simple solution. It involved attaching a VELCRO strip along the belly strap of a larger-sized vest such that, if it had to be shortened, it could simply be folded onto itself and attached as usual (Fig. 14).

Fig. 14. The folded strap mechanism was made to account for dogs of multiple sizes.

Training the “Help” Command

The training of the “help” command was meant to instruct dogs in the task of activating the sensor in the proximity of the human being pointed to. The dog should move toward this individual and alert him or her by activating the wearable sensor (i.e. tug). The “help” cue given by the human should be consistent across trials (a pointing gesture and the word "help").

We learned that it was simpler to train the task in two stages. First, the dog learned to leave the handler and request help, without activating the sensor. We realized that starting with small distances yielded better results, especially considering that most working dogs we’ve had contact with are hesitant to leave the person they were working with and receiving rewards from.

To alleviate this, we discovered that it was beneficial to have the "stranger" reward the dog for a successful approach and also have the original human reward the dog when coming back. Once this pattern was successfully established, adding the requirement of tugging the sensor, trained separately, was much easier.

Because training the dogs to leave the human partner required more time than we anticipated, we did not compute performance metrics for this portion. Nonetheless, the insight we gained from training this aspect provided some of the most interesting findings. Although not documented, one service dog user was able to train her dog (using the first two prototypes) during the span of one week to achieve almost perfect activations to alert familiar individuals standing nearby. We have yet to study the difficulty of alerting unfamiliar individuals who are walking within the line of sight of the owner and service dog.

Audio Considerations

Our initial prototype used a female voice to communicate alerts; because we hypothesized higher pitch voices would carry better in outdoor environments. Nonetheless, most users said they wanted their dog's voice and sex to match. Finally, bystanders stressed that the "help" message must seem trustworthy (not sound like a prank or practical joke).

Results

Following the performance metrics from our previous experiments (Jackson et al.), we analyzed the videos and computed the following individual metrics of accuracy for both the sensor and the dog.

Dog Accuracy (DA): DA calculates accuracy for dogs as

$$DA = \frac{N - D - S - I}{N} * 100$$

N = Number of cues from owner to dog

D = Deletions, dog did not attempt to activate

S = Substitutions, dog performed wrong action (such as reaching to the opposite side)

I = Insertions, dog activated without a cue

Sensor Accuracy (SA): SA calculates accuracy of the sensor as

$$SA = \frac{N - D - I}{N} * 100$$

N = Correct attempts (tugs) from the dog

D = Deletions, sensor did not activate

I = Insertions, sensor activated without interaction.

These metrics were intended to handle borderline cases that are not a strict success or failure. These include cases where a dog might reach for a sensor two times but only grabbed once; cases where the dog grabbed the sensor twice, but tugged once (one incomplete attempt followed by a completed attempt). Other borderline cases involved the dog activating multiple times per cue or the dog ignoring a cue altogether.

Finally, we employ a global metric to quantify the effectiveness of the system in these experiments (overall success). Unlike dog accuracy (DA), this last metric does not decrease with multiple successful activations per cue because this behavior would be beneficial in a real-life scenario.

Overall Success: $OS = \frac{A}{N} * 100$

N = Handler intents (cues)

A = Successful Activations

Compared to our previous results, we were able to improve on all performance areas, specifically on sensor accuracy (Table 2). The marginal improvement on Dog Accuracy is expected considering that dog's understanding and obedience of the task was not affected directly by the vest. Nonetheless, we note that due to being distracted by the environment S2 had a lower dog accuracy score despite understanding the task. Additionally, we tested the system for false positives while a dog carried out everyday activities for the span of an hour. This included waking, going up and down a set of stairs, playing, and lying down. No false positive activations were detected.

Table 2. Tabulated results were computed for each performance metric for each dog subject. The tug sensor results from this experiment are an improvement over the previous design (Jackson, et al.).

Dog	Dog Accuracy	Sensor Accuracy	Sensor Reachability	Overall Success
S1	91%	91%	82%	82%
S2	69%	92%	92%	100%
S3	90.1%	90.9%	100%	90%
Current Total	84%	91%	91%	91%
Previous	83%	60%	87%	84%

Conclusions

We have presented a series of prototype vests to support the task of alerting or getting help by mobility-assistance service dogs. We improved on the results from previous work in each of four performance metrics while maintaining a rate of zero false positives in the span of an hour of activity. We presented solutions to some practical issues necessary for achieving more reliable and consistent experimental results. We have also documented our conversations with active service dog users with regards to technical, social and canine considerations, which should be useful for future studies. Further studies should examine the possibility of a system that could integrate into a service dog's existing collar. This would allow the dog to comfortably wear the sensor at home without the need for a full vest. Some of the challenges to be addressed with this approach are the reliable activation of a sensor from the collar and the use of small speakers that are sized for a collar yet are still loud enough to convey the required message. Until such challenges are addressed, we believe that configurations like the ones examined in this study are the most promising.

Acknowledgements

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