Facilitating Interactions for Dogs with Occupations: Wearable Dog-Activated Interfaces

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ABSTRACT

Working dogs have improved the lives of thousands of people. However, communication between human and canine partners is currently limited. The main goal of the FIDO project is to research fundamental aspects of wearable technologies to support communication between working dogs and their handlers. In this pilot study, the FIDO team investigated on-body interfaces for assistance dogs in the form of wearable technology integrated into assistance dog vests. We created four different sensors that dogs could activate (based on biting, tugging, and nose gestures) and tested them on-body with three assistance-trained dogs. We were able to demonstrate that it is possible to create wearable sensors that dogs can reliably activate on command.

Author Keywords

Wearable technology; Animal-Computer Interaction

ACM Classification Keywords

H.5.2 [Information interfaces and presentation]: User Interfaces---user-centered design.

General Terms

Design, Human Factors.

INTRODUCTION

Melissa and her guide dog Roman are walking along a familiar sidewalk when Roman suddenly stops. Melissa asks him to go on, but Roman refuses. Melissa checks for obstructions with her collapsible cane, but feels nothing in their path. "What's up, Roman?" Roman tugs a tab on his harness and the message "go around" sounds in Melissa's earbuds. Roman finds a safe route off of the sidewalk, avoiding the wet cement in their path.

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Charles is engrossed in a movie in his dark home theater when his hearing dog, Schubert, alerts. "What is it, Schubert, the doorbell?" Charles asks, and Schubert touches one of the four buttons on his vest with his nose. A message appears on Charles' head-mounted display. "Tornado siren? Oh my!" As they immediately head to the basement, Charles praises Schubert for the warning.

Police sergeant Sarah Gray knows that time is of the essence as she gives a hand signal to her Search and Rescue dog, Stryker. As Stryker begins a sweep of the woods off to his right, he picks up a familiar scent and follows it, running faster as it gets stronger. In a small hollow he locates his target: the 6-year-old child who wandered away from her family's campsite. He grabs a rectangular object dangling from his collar and begins to bite it. The object activates a GPS communicator on his vest, geo-locating and transmitting his position to his handler and a medical team standing by. A tone tells Stryker that his work is done, and he lies down waiting for his handler and her team to arrive.

The scenarios above are just a sampling of the many ways dogs could use wearable electronics to communicate with humans. Dogs currently work in many ways: guide dogs serve people with visual impairments [15]; service dogs aid people with physical disabilities [1]; hearing dogs alert people with auditory disabilities to sounds; Search and Rescue dogs can locate people who are lost. These highly trained canines perform critical, even life-saving tasks.

The main goal of the FIDO project is to research fundamental aspects of wearable technologies to support communication from working dogs to their handlers. This paper describes a pilot study of four different on-body sensors that allow dogs to give information to their handlers. We integrated electronics into dog clothing to create canine user interfaces. We tested these interfaces with three assistance-trained dogs to evaluate ease of interaction, error rate, and false positive rate.

BACKGROUND AND RELATED WORK

Although animals have operated machines since the time of Skinner [16], Animal-Computer Interfaces (ACI) are relatively new. Recently there has been interesting work on "interspecies interaction", including games, remote monitoring, and remote interaction. Games such as "Cat Cat Revolution" [9] and "Feline Fun Park" [20] allow humans to play with cats mediated by computing. The "Canine Amusement and Training" (CAT) system focuses on games as a way to teach humans to train and interact with dogs [19]. Remote interaction systems allow a human to monitor, care for, and play with their pets at home when they are away [5, 4, 8]. Dog-mounted GPS and video cameras can give their owners a perspective on the dog's experiences in the household [7] and hunters interacting with their working dogs [10, 18]. Researchers have trained an assistance dog to take commands from a speaker worn on his body [14]. While some of these studies support handler-to-dog communication or monitoring, they have not yet explored dog-to-handler interactions.

METHODS

We performed a pilot study to determine which types of sensors dogs can most easily understand and interact with. We based four different sensor designs on natural capabilities of dogs – biting, tugging, and touching with the nose. Our eventual goal is to support multiple sensors on the dogs' vests to communicate a variety of messages. However, for consistency in this pilot study, we tested each sensor individually in the same location on the left ribcage area of the dogs' vests. For each sensor, we measured the sensor readings during a series of dog interactions, as well as during normal assistance dog activities (to test for false activations). We then calculated performance metrics for both the dogs and the sensors.

Sensors

We tested the sensors with the Arduino Teensy or Lilypad microcontrollers [17, 6]. These are both based on the 8-bit Atmel AVR Atmega architecture and have similar specifications. All sensors produced analog readings that were input to the analog pins in the microcontrollers and converted to a 10-bit digital value. For each sensor, we set an a priori threshold value for activation. Once this threshold was met, a piezoelectric buzzer attached to the microcontroller emitted a tone. This auditory feedback allowed both the dogs and their handlers to know that a successful activation had occurred. On every loop cycle, the analog sensor reading was recorded and stored externally for post-processing on a microSD card. We created two bite sensors, one proximity (gesture) sensor, and one tug sensor.

Bite Sensors

We used force sensitive resistors (FSRs) [2] and a 3D-printed enclosure to construct two different shaped bite sensors: an oval and a rectangle. Each bite sensor had a 0.16" (4 mm) diameter active sensing area and varied its resistance depending on how much pressure was applied to the sensing area. The harder the force, the lower the resistance. When no pressure is applied to the FSR, its resistance is larger than 1MΩ; with full pressure applied the resistance is 2.5kΩ.

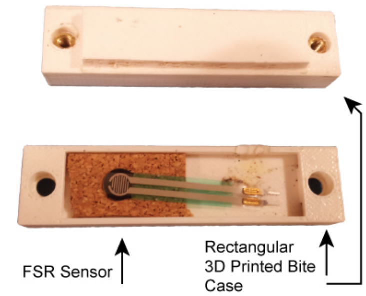

Figure 1. Rectangular case for FSR sensor.

Rectangular bite sensor - The motivation for the rectangular bite sensor was to simulate the form factor of a "bringsel", which is a padded stick attached to the collar of a Search and Rescue (SAR) dog. When a SAR dog finds its target, it holds the bringsel in its mouth and returns to the handler. To achieve this, the bite sensor (Figure 1) was covered in nylon fabric with two pieces of colored fabric identifying the top and bottom (Figure 2).

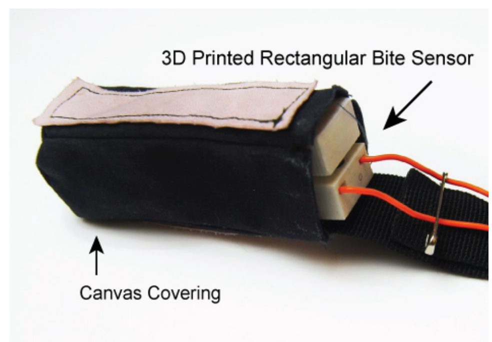

Figure 2. Rectangular bite sensor with fabric cover.

We attached the sensors on the left side of a dog vest, using nylon straps linked to a metal ring on the vest (Figure 3). All sensors were placed in a manner similar to that illustrated in the figure. We chose this location because it would be accessible to a wide range of dogs, per the recommendation of our dog training experts.

Figure 3. Retriever with vest and rectangular sensor on left side configuration.

Oval bite sensor - The oval form factor for the FSR case was internally similar to the rectangular version; the difference lay in the external appearance. In this case, the bitable surface area was larger in order to ensure that the dogs bit the sensor perpendicularly to its surface rather than in a parallel fashion. In order to make the casing more inviting for biting, it was covered in black rubber material as shown in Figure 4.

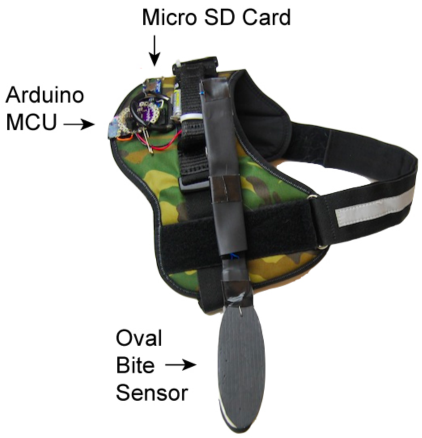

Figure 4. Oval bite sensor with microprocessor on vest.

The dogs activated the bite sensors by reaching around to grab the sensor, performing a quick bite, and then letting go, as shown in Figure 5.

Figure 5. Border Collie activating oval bite sensor on-body.

Proximity sensor

Our proximity sensor utilized an ultrasonic range finder with an analog output, which was set to detect movement at a distance of less than three centimeters. A small conical shield around the sensor protected it from activating too easily from objects in the environment, as shown in Figure 6. The dog placed its nose directly over the sensor to activate it.

The proximity sensor was wired to one of the analog pins on the microcontroller to capture the sensor values as objects moved towards and away from the sensor. In order to detect object distance, the microcontroller implemented a moving average of fifty readings and produced a beeping sound if that average was lower or equal to the pre-set threshold. The buzzer would beep if an object was in front of the sensor for half of a second and turned off once the object moved away approximately eighteen centimeters.

Figure 6. Proximity sensor on dog vest.

Tug sensor

The tug sensor consisted of a 10 cm stretchable rubber variable resistor sewn into an elastic band, which was in turn sewn to a small commercial dog toy (Kong "Wubba") as shown in Figure 7. The dog activated the sensor by grasping and tugging the toy with his teeth. The sensor detected the force of a dog pulling on it and, like the previous sensors, triggered a beeping to sound if the force applied exceeded a threshold.

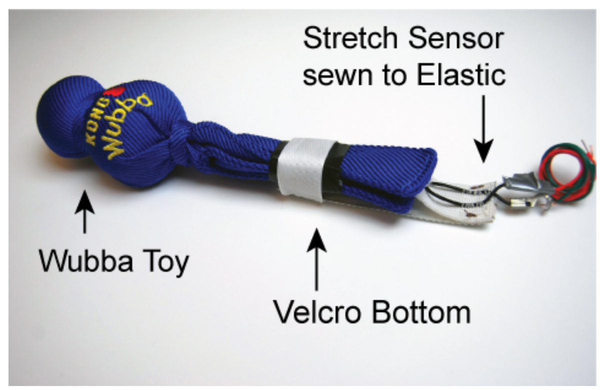

Figure 7. Tug sensor showing variable resistor sewn into elastic.

The tug sensor was designed to be strong enough to compensate for the fragility of the stretch-sensing resistor, yet sensitive enough to register a tug by the dog's mouth. This compromise was achieved by sewing the resistor into an equal length of elastic. Because the elastic was not as stretchable as the resistor, and was also much more durable in terms of withstanding pulling force, it enabled the tug sensor to stretch enough to change its resistance but not enough to break it as the dog pulled on it. This apparatus was mounted on the side of the dog's vest, as shown in Figure 8.

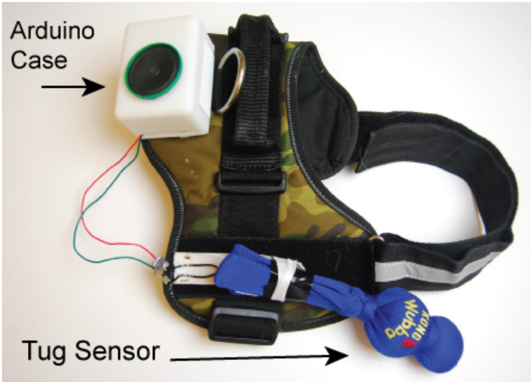

Figure 8. Tug sensor on vest.

To activate the tug sensor, the dogs reached around and grasped the ball of the dog toy, gave a brief tug, and released, as shown in Figure 9.

Figure 9. Border Collie activating tug sensor on-body.

Dog Training method

For this study, we selected dog subjects trained in certain skills: hand-target (touch the handler's hand with the nose), retrieve ("get it", grasp an object and bite down), and tugging (grasp an object and pull). All of the dogs had already been trained with operant conditioning techniques [16], specifically *shaping*, which is building new behaviors by selectively reinforcing behaviors the dog offers [8]. For the experiment, we only used positive reinforcement; we did not employ correction or punishment.

We classically conditioned [11] the dogs with high-value reinforcement (food) to a verbal reward marker, such as the word "yes". By marking desired behaviors at the moment of execution, we shaped the dogs towards the final interaction goal for each sensor.

Sensor-specific training for this experiment began with off-body interactions. The handler presented the sensor to the dog and verbally encouraged him to interact with it. When the dog offered an appropriate behavior (for example, taking a bite sensor in his mouth), the behavior was marked and the dog received a treat. Next, the dog was required to bite harder on the sensor to receive a treat, until the sensor was activated. All three of the dogs learned to operate each sensor in a matter of minutes with this method. Once the dog learned to operate each sensor off-body, we attached the sensor to the dog's vest on the left ribcage. Through a series of hand-targets, we taught the dogs to find and activate the sensors on their bodies, shown in Figure 9. All dogs were proficient with each sensor after one training session. Training and testing sessions were no more than fifteen minutes, and no more than four sessions were held throughout a day with thirty minutes rest in between.

Subjects

As summarized in Table 1, we tested the sensors with three assistance-trained dogs. BC1 is a Border Collie, raised with assistance dog training but currently working as a competition agility dog. BC1 has extensive experience with shaping techniques and is very proficient with agility tugging and retrieving. Agility tugging and retrieving is very vigorous; it is intended to arouse the dog for work. BC2 is a Border Collie and is an active assistance dog. BC2 also has competition agility training and is very familiar with shaping, tugging, and retrieving. R1 is a Golden/Labrador cross retriever. He is an active service dog trained with traditional techniques. He is familiar with shaping but is trained for precision tugging and retrieving, which means he tugs very carefully (for tasks such as removing his handler's socks) and retrieves with a very soft bite.

Dog	BC1	BC2	R1
Breed	Border Collie	Border Collie	Retriever
Training	Assistance Agility	Assistance Agility	Assistance
Sex	Male	Male	Male
Age	5	3	4
Weight	20.41 Kg	15.88 Kg	31.75 Kg

Table 1. Subject demographics.

Experimental Protocol

Initial Testing Session - Each dog participated in one training and one testing session for each sensor tested. All test sessions were videotaped for post-processing. After turning on the SD card recording data from the sensors, we performed a synchronization trigger (human activating the sensor) for time synchronization with the video. Each session consisted of the handler asking the dog to activate the sensor approximately ten times. After the corresponding attempts, the experiment concluded with another synchronization trigger. Similar to the training sessions, test sessions took approximately 10-15 minutes.

Normal Activity Session - Thirty-minute false positive tests were performed with one subject (BC1) for each sensor. The dog wore the sensor during normal assistance dog activities, walking in a building, going up and down stairs, jumping up onto a bench, and walking outside on city streets. The dog was allowed to interact with people and other dogs during the test, and to lie down and sit occasionally. We videotaped the dog and recorded the sensor values for the entire 30 minutes.

RESULTS

To understand activation patterns for each sensor/dog combination, we used time-based activation graphs similar to the ones in Figures 10, 11, and 12. The graph in Figure 10 shows an example of an experiment with the oval-shaped bite sensor. The threshold (shown in red) was set at the halfway point on the pressure scale of both the oval and rectangle shaped bite sensors. The tug sensor activation pattern is illustrated in Figure 11. For this sensor, the threshold was determined empirically and is also shown as a red line. The proximity sensor's value corresponds to the distance of the nearest object, as shown in Figure 12. As a result, the y-axis is inverted in comparison to the other sensors. Activations are indicated by the sensor value decreasing below the distance threshold (rather than exceeding it).

Performance Metrics

To evaluate the sensors, we used several metrics. We describe each one and a comparison of the four sensors below.

Dog Accuracy (DA): We calculated accuracy for dogs as DA = (N – D – S – I)/N * 100, where:

N = Number of commands from handler to dog
D = Deletions, dog did not attempt to activate
S = Substitutions, dog performed wrong action
I = Insertions, dog activated without command

This metric determines the subject's understanding of the sensor interaction task. It does not require sensor activation, only correct interaction with the sensor. Table 2 below summarizes the DA results:

Dog	Bite Oval	Bite Rectangle	Tug	Proximity
BC1 **(N, D, S, I)**	73% (15,1, 0, 3)	100% (14,0,0,0)	64% (14,5,0,0)	100% (10,0,0,0)
BC2 **(N, D, S, I)**	92% (13,0,0,4)	100% (10,0,0,0)	100% (11,0,0,0)	80% (10,0,0,2)
R1 **(N, D, S, I)**	65% (20,1,6,0)	83% (12,1,1,0)	100% (10,0,0,0)	42% (26,14,1,0)

Table 2. Dog Accuracy for each sensor.

Sensor Accuracy (SA): SA calculates accuracy of the sensor only. For this metric, SA = (N – D – I)/N * 100, where:

N = Correct attempts (bites, tugs) from the dog
D = Deletions, sensor did not activate
I = Insertions, sensor activated without interaction

Table 3 compares the SA of each sensor.

Dog	Bite Oval	Bite Rectangle	Tug	Proximity
BC1 **(N, D, I)**	88% (17,2,0)	64% (11,4,0)	66% (12,4,0)	100% (12,0,0)
BC2 **(N, D, I)**	77% (14,2,0)	64% (11,4,0)	36% (13,8,0)	90% (10,1,0)
R1 **(N, D, I)**	50% (12,6,0)	0% (10,10,0)	100% (10,0,0)	100% (11,0,0)

Table 3. Sensor Accuracy for each sensor.

Sensor Reachability (SR): This metric quantifies the difficulty associated with reaching the sensor due to its placement on the body. It is calculated as SR = N / A, where:

N = Number of attempts to access the device.
A = Number of successful acquisitions (regardless of activation)

Perfect score for SR is 1.0. Values above 1.0 indicate higher difficulty. Table 5 summarizes these results.

Dog	Bite Oval	Bite Rectangle	Tug	Proximity
BC1	1.06	1.27	1.09	1.16
BC2	1.00	1.10	1.00	1.18
R1	1.77	1.11	1.00	1.00

Table 4. Sensor Reachability for each sensor.

Overall Success (OS) – This metric quantifies how many "handler intents" (commands) resulted in successful activations. This metric combines dog and sensor accuracies, calculated as OS = A / N, where:

N = Handler intents (commands)
A = Successful Activations

Table 4 summarizes the results.

Dog	Bite Oval	Bite Rectangle	Tug	Proximity
BC1	87%	70%	36%	86%
BC2	92%	70%	45%	90%
R1	30%	0%	100%	42%

Table 5. Overall Success for each sensor.

False Positive Study

In order to quantify the false positive vulnerability of each sensor, we conducted a "normal activity" field study for a period of 30 minutes. We recorded each session on video and analyzed the video to attempt to determine the cause of the false activations. Table 6 summarizes these results.

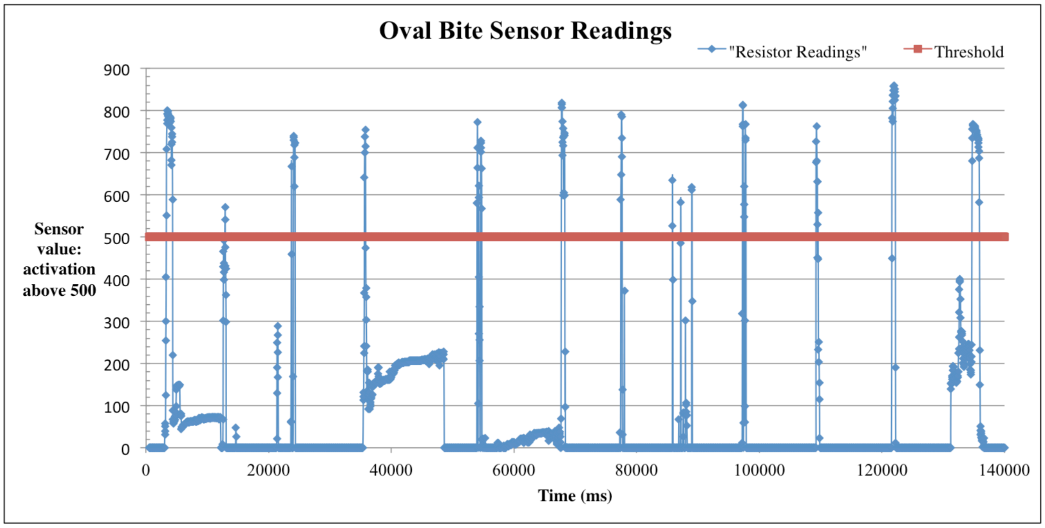

Figure 10. Sensor activation graph for oval-shaped bite sensor.

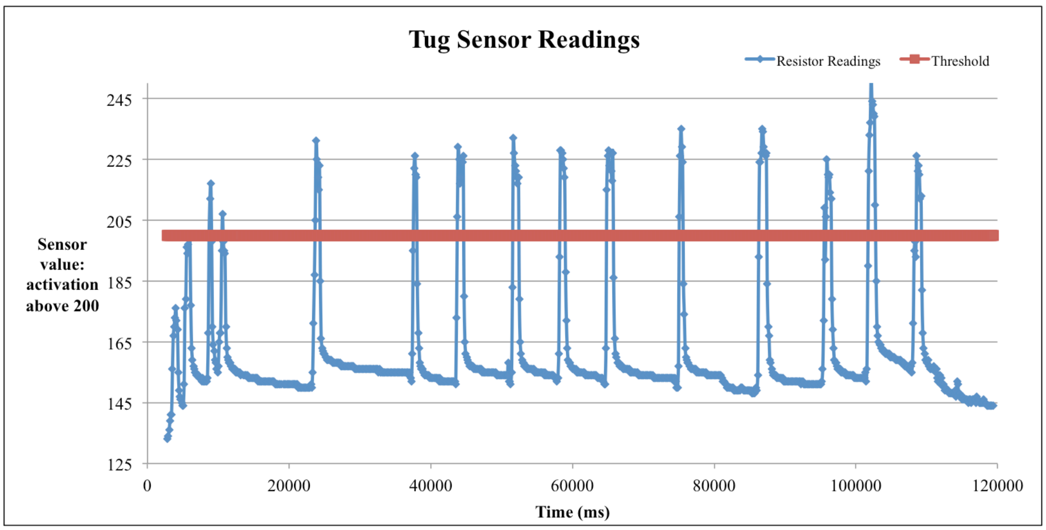

Figure 11. Sensor activation graph for tug sensor.

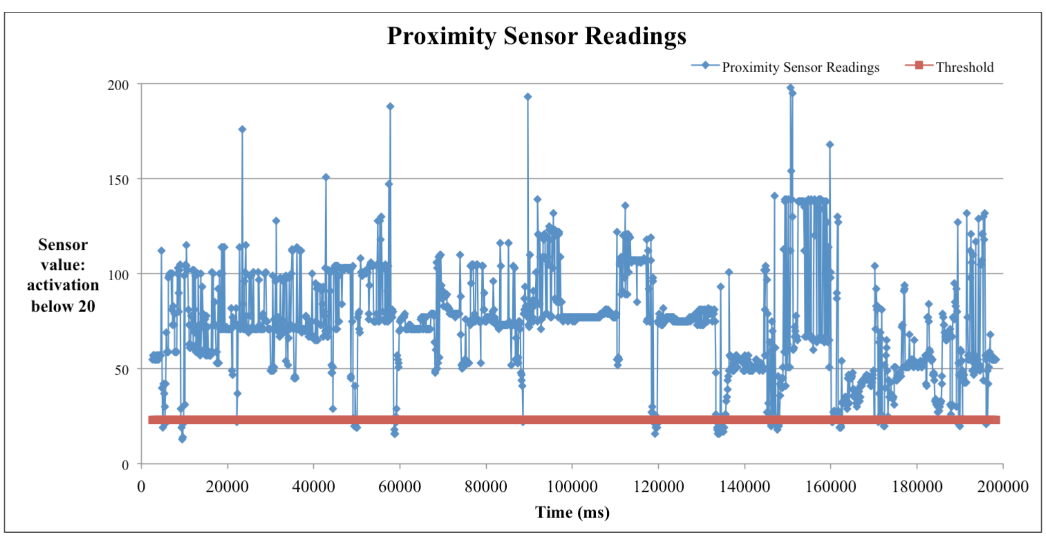

Figure 12. Sensor activation graph for proximity sensor.

Sensor	FP/30min	Causes of FP
Bite Sensor, Oval	2	Lying on sensor
Bite Sensor, Rectangle	0	None
Tug Sensor	1	Dog shaking body
Proximity Sensor	8	Doors, Objects nearby, Going up stairs

Table 6. Summary of false positives (FP) from normal activity study.

The rectangular-shaped sensor had no false positives, and the tug sensor had one when the dog vigorously shook his entire body, flinging the sensor around as well. The proximity sensor activated when the dog walked too close to objects in the environment, such as touching a table.

Conventions

In analyzing the video data, we used the following conventions. Multiple commands from the handler for a single intent were counted as one. We did not penalize unsuccessful activations from the vest slipping, or distractions external to the experiment. We slightly altered the angle of the proximity sensor for subject R1 to compensate for subject's larger anatomy. Additionally, R1 learned to begin activation upon hearing the video narrator. We included these as valid commands.

DISCUSSION

Sensor Comparison

In terms of dog accuracy, which measures dog understanding of how to activate the sensor, the rectangle bite sensor was the best. All of the dogs were previously trained to retrieve so this was a natural interaction for them. In terms of sensor accuracy, the Proximity sensor was the clear winner in the activation tests, with an average of 97% for all three dogs. However, it also exhibited the greatest number of false positives (8). This increased rate illustrates a predictable tradeoff between accidental activation and ease of activation. Similarly, the oval bite sensor data shows a tradeoff between reachability and ease of activation. The longer the sensor hangs from the vest, the easier it is to reach while also becoming more susceptible to the dog lying on it. Previous training had a profound effect on the bite sensor results. R1's precision retrieve meant he did not bite hard enough to activate the sensors. The agility dogs had much more success with their more vigorous bite. The rectangular bite sensor was inferior to the oval bite sensor in activation most likely due to mechanical flaws that will be addressed below. R1's precision tug gave him an advantage on the tug sensor, with 100% overall accuracy.

Dog Training Effects

The dogs quickly learned that the tone was the actual marker for success and would sometimes continue to attempt to activate the sensor until they heard it, without commands from the handler. This implies that feedback to the dog is extremely important for consistent activation. It also means that sometimes the dogs would activate the sensors more than once per command. Our accuracy metrics penalize these extra activations. However, in real world usage, the extra activations would most likely not be an issue.

All of the dogs were already trained to tug and retrieve before the experiment, so training the dogs on the bite and tug sensors was relatively easy. We observed an interesting learning progression with all three dogs on the proximity sensor. Both border collies discovered, on their own, that they only needed to wave their nose past the sensor, rather than trying to touch it or bite it. A few minutes into the training session, the dogs were clearly performing gestures with their noses, which was not a previously trained skill. Nose gestures could represent a straightforward method for extracting multiple signals from a single sensor (such as down to up, or up to down).

Subject R1 learned that spinning (a skill he was already trained to do) activated the proximity sensor. Even though this behavior was not optimal, it still resulted in a valid activation and was subsequently rewarded. In a real usage scenario we would take time to extinguish this behavior.

Sensor Improvements

Bite sensor improvements - Our preliminary experiments point to two areas where the bite sensors can be improved in order to achieve better results. The first and most important involves the directionality of the biting action. Due to the flat nature of the underlying FSR, and the case covering it, pressure has to be applied perpendicular to the surface. The rectangular sensor casing did not suggest that one direction was preferred over the other, and as a result dogs tended to bite it in any direction. The oval sensor had better affordances for bite direction, but when the dogs attempted to activate the sensor, they sometimes grasped it with an imperfectly aligned bite. The dogs quickly learned to shift the sensor in their mouths, but activation was much less efficient. We are developing a multi-sided bite sensor that can be activated from any angle to address this issue.

Second, when biting the sensor cases, dog tended to look for an "anchor point" to allow for a stronger grasp. On the rectangular sensor, this anchor point were the screw-holes along the top of the case. Unfortunately, biting the screws transfers the force directly to the other side of the sensor, bypassing the FSR and decreasing the sensor accuracy.

Tug Sensor Improvements - Because the tug sensor was attached to a dog toy, it was very intuitive for the dogs to find and correctly interact with it. However, the sensor did not consistently activate. This result could have been due to an activation threshold that was set too high, or possibly the design of our apparatus not being flexible enough to stretch the sensor to the point of activation.

Calibration - An important difference among our three test dogs was bite and pull strength. For example, the two Border Collies had no problems with the bite sensor, whereas the retriever's softer mouth initially did not bite hard enough to pass the threshold, although he was otherwise performing a correct bite. An automated calibration of bite and tug force, using machine learning techniques and a number of training samples, could help to adjust the sensitivity of the sensor appropriate to the dog.

Proximity Sensor Improvements - The proximity sensor could be improved by adding an adjustable range to customize its sensitivity for the dog and the environment. Alternatively, an infrared alternative might reduce triggers from inanimate objects. We also could locate the sensor in a different area, such as under the neck, which would make it less vulnerable to triggering on objects such as doorways.

Sensor locations - Anatomical differences are an important facet in designing sensors for dogs. Border collies are very flexible and can reach almost anywhere on their bodies. Retrievers and other larger dogs, however, are thicker through the neck and torso and may not be able to easily reach items that are close to their heads. Therefore the sensors need to be reachable by the target dog breed. Further studies should include placing each sensor in different locations on the dog vest, or on a coat or sleeve.

CONCLUSIONS AND FUTURE WORK

The results of this pilot study are extremely encouraging; we demonstrated that it is possible to create wearable electronics that dogs can reliably activate to communicate with their handlers. There is a vast amount of work yet to be done. The sensors need to be smaller and more robust, and require less power. We need to examine sensor placement bilaterally and beyond the ribcage area, to determine what locations are reachable by different dog body types, and to determine the optimal area for each sensor type. Along with the sensor placement study we need to discover the best ways to train the dogs to differentiate multiple sensors on their bodies, and to activate them on different environmental triggers. We plan to explore other sensors, such as "Touch-points", which are areas embroidered with conductive thread that could be activated with a simple nose or paw touch. We also plan to stress-test the designs with dogs at speed on an obstacle course, which could simulate a rugged outdoor environment. This technology could easily be adapted to other canine professionals, for Police work (bomb and drug sniffing dogs could report their finds) and Military Working Dogs who could communicate the location and type of Improvised Explosive Devices (IEDs). Providing dogs with the ability to communicate clearly to humans opens a myriad of possibilities.

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