THE INTERNET OF LIVING THINGS: ENABLING INCREASED INFORMATION FLOW IN DOG–HUMAN INTERACTIONS

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THE INTERNET OF LIVING THINGS: ENABLING INCREASED INFORMATION FLOW IN DOG–HUMAN INTERACTIONS

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To Antone Sylvia, my Vavo,

for guiding and inspiring me,

to become one "helluva engineer."

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SUMMARY

The human–canine relationship is one of the oldest relationships between a human and an animal [13]. Even with this longevity and unique living arrangement, there is still a great deal that we don't know about our dogs. What do we want to know and how can computing help provide avenues for dogs to tell us more? To address the question of "what do people wish their dogs could tell them?" In an unpublished survey of UK dog-owners, the most frequent request was to know about their dog's emotional state and the most frequent response regarding what they wish their dogs would tell them was about what they love and what they are thinking. These responses dominated the survey, outnumbering even the responses regarding the dog's physical needs like toileting. This hunger for more and better information from dogs has created a boom in the number of devices targeting these desires with unverified claims that have appeared on the market within the past 5 years. Clearly there is a need for more research, particularly in computing, in this space. While my dissertation unfortunately does not provide a love–detector or dog–thought –decoder, it does lay out the space for what wearables on dogs could provide today and in the near future. My focus is on addressing the information asymmetry between dogs and people, specifically by using wearable computing to provide more and richer information from the dog to more people. To do this, I break down the space into three categories of interactions. Within each of these categories I present research that explores how these interactions can work in the field through prototype systems. This area of research, Animal–Human–Computer Interaction is new, and the area of Canine–Centered–Computing is younger still. With the state of these fields in mind,

that my goal with this dissertation is to help frame this space as it pertains to dogs and wearable computing.

CHAPTER I

INTRODUCTION

Despite an eleven-thousand-year-old coexistence between humans and dogs, the flow of information between these two species is highly asymmetrical [14]. This asymmetry can be traced, in part, to three barriers. We have classified these as perceptual, distance and contextual barriers [124].

Perceptual barriers are a result of humans being unable to perceive information from sensory modes not used for human communication (e.g., scent).

Distance barriers are present when the humans are beyond line of sight (or hearing) to make direct observations. For example, humans in a work environment are unlikely to notice their dog is exhibiting distress behaviors at home (e.g., constant barking) [99].

Contextual barriers are manifest when a behavior is undecipherable by a human due to a lack of context or expertise. For example, yawning in the absence of context can be interpreted as tiredness. Additional information, such as the onset of a thunderstorm, clarifies that this behavior could have a different cause, namely stress. Similarly, because a dog's human companions are the most likely to understand this contextual information, the potential to communicate to humans other than their companions is limited.

These three barriers cause the aforementioned information asymmetry. The field of information technology has a long history of overcoming such asymmetries, and so, I propose using wearable computing systems for this purpose.

1.1 Thesis Statement & Research Goals

I present the following thesis statement:

Wearable computing systems increase the quantity and quality of information, its accessibility, and the number of recipients in dog–human interactions.

Through this research, I aim to advance our understanding of how wearable computing technology can be used to address the information asymmetry between humans and dogs. Throughout my dissertation, I seek to accomplish these research goals:

1. Create new modes of dog–human interaction with wearable systems.
2. Design systems and actions that support these interactions.
3. Improve the information flow in dog–human interactions through wearable systems.

For my first research goal- *Create new modes of dog–human interaction with wearable systems.* I propose two solutions:

1. Wearable systems can support short-term interactions for communicating a specific message and long-term interactions for monitoring.
2. Wearable systems can support interactions for collaboration.

To examine these, and address the first research goal, I describe *Descriptive, Diagnostic and Directive* interactions that are facilitated by wearable computing [10]. *Descriptive* interactions allow dogs to send a specific message to humans. *Diagnostic* interactions allow humans to understand canine actions on a broader scale. Finally, *Directive* interactions support decision-making in collaborative canine–human systems, such as explosive-detection teams. This framing will be used to categorize my work throughout the document.

For my second research goal- *Design systems and actions that support these interactions.* I have three components:

1. The design should be created alongside practitioners in the system domain.
2. Wearable computing systems for dogs should use the minimum amount of equipment and not limit their movement.
3. Distributed Cognition and Contextual Design are useful tools in designing systems that support humans and dogs.

This research goal is primarily addressed by work found in the *Descriptive* chapter, although there are systems that support these components also found in chapters four and five.

For my third research goal - *Improve the information flow in dog–human interactions through wearable systems.* I have three components:

1. Wearable systems increase the quality and quantity of information in a kenneled and home environment.
2. Wearable systems increase the *number of recipients* of information in work environments.
3. Wearable systems increase information *accessibility* in kenneled and home environments.

This research question is addressed by work found in the *Diagnostic* chapter and *Directive* chapter. A chart of my research goals can be found in the Appendix. Figure 15.

1.2 Contributions

There are few technologies that exist for facilitating improved information flows between dogs and humans. I will demonstrate how technologies may use and act on data from dogs in systems that include both humans and dogs. I will show how wearable systems improve (or create) forms of interaction that increase the quantity, quality and accessibility of information in dog–human interactions. My research will contribute:

- Creation of systems to support Descriptive, Diagnostic, and Directive interactions between dogs and humans (Chapters 3, 4, and 5).
- Guidelines for developing technology created for dogs (Chapter 6).
- A framework for implementing systems that facilitate improved information flows between humans and dogs (Chapter 6).
- A data set on working dog puppy movement and rest patterns generated from inertial data from 8 weeks to 18 months of age (Chapter 5.2).
- Design of Puppy Accelerometer Data for Working Dog Suitability (PAWS) system (Chapter 5.2).
- A statistical and qualitative analysis of PAWS for the purpose of working dog training outcome prediction (Chapter 5.2).
- An analysis of the influence of PAWS on dogs in working dog training environments and of their assessments by working dog practitioners (Chapter 5.2).

1.3 Roadmap

This dissertation is divided into seven chapters. Chapter 2 discusses related work from veterinary medicine, animal behavior, and computing. Chapter 3 describes my work with Descriptive interactions, systems created for dogs to send specific messages to humans. Chapter 4 describes my work with Diagnostic interactions. In this chapter the systems are used to passively monitor the dogs to provide the humans more information about what the dog is doing when they are unobserved. Chapter 5 explores initial work with Directive interactions. In it, I describe a system that was built for law enforcement users, both human and canine, to communicate while on a search task. A second system, PAWS, Puppy Accelerometer for Working dog suitability is described alongside the process of its design. Chapter 6 reflects on this thesis and reviews the design principles as well as provides guidance for future direction of the field. Chapter 7 contains the conclusion.

CHAPTER II

BACKGROUND AND RELATED WORK

2.1 What Veterinary Medicine Teaches Us About Dogs

Although there is no other species on earth that varies anatomically more than the dog, there are general lessons from veterinary medicine about dogs that are important to be understood when designing or evaluating systems for them [13]. One of these lessons helps us to define the dog's sensory bounds. For example, one key limitation that must be understood when designing for dogs is what colors are easily visible to them, blue and yellow, and what are the extent of the monocular and binocular visual fields in a typical mesocephalic and brachycephalic dogs [80, 87].

Knowing what colors dogs can see and the extent of their visual field is particularly helpful when designing affordances and signifiers. My notion of affordances and signifiers comes from Norman's text in which he provides fundamental interaction principles and guidelines for designers [89]. Norman defines affordances as "the possible interactions between people and the environment," and says that they do not always have to be perceivable. He defines signifiers as signals to "what actions are possible and how they should be done," and states that they must perceivable in order to function (p. 19). Affordances for dogs should be perceivable continuously due to their limitations around object permanence as described by Cooper et al., [24]. It is crucial that signifiers are clear and within canine sensory bounds. Norman's error design principles of putting "the knowledge required to operate the technology in the world, and using "the power of natural and artificial constraints" (p. 216) are also applicable to dogs, although it is important to note the difference between canine memory compared to human memory when it pertains to handling operational knowledge and error recovery [131].

Veterinary medicine has also provided a framework for understanding canine movement and a dog's anatomy. This has been particularly helpful when embarking on studies, such as the one I presented on Canine Reachability. In this study, which can be found of Chapter 3 of this document, I examined where on a dog's body an interface should be placed if they must physically activate it [120].

2.2 Dog–Human Bond

The bond between dogs and humans and how this relates to their interactions with one another is a well researched area, particularly in how the dogs react to human behavior [63]. The effect of training methods on the dog–human relationship has also been studied with positive reinforcement, the method of training I use in my research, providing less stress for dogs than negative reinforcement [29]. This work by Dedalle compares the stress the dog experiences during training when positive reinforcement and negative reinforcement are used. Positive punishment was not compared in this study as the stress effects from this method are well established. From a working dog perspective, the relationship and bond between dogs and humans has been examined to see how these relationships affect the dog–human team in working tasks such as searching tasks [56]. Lastly, recent work by Siniscalchi, Stipo, and Quaranta suggest that the dog–human bond can be characterized as an "attachment" [109]. Their work investigated possible associations between the owners' attachment profile and the owner-dog attachment bond which was evaluated using a modified version of Ainsworth's "strange situation" [2].

2.3 Theorizing on Animals and People

2.3.1 Haraway

Theorizing of the meeting between animals and humans can best be summed up by Haraway [47]: "A great deal is at stake in such meetings, and outcomes are not guaranteed. There is no teleological warrant here, no assured happy or unhappy ending, socially, ecologically, or scientifically. There is only the chance for getting on together with some grace." Her work has been foundational in making explicit the demands we as humans, place on animals. In *When Species Meet*, Haraway continues by describing the notion of *becoming with* as the 'dance' between subject and object that happens when species are knotted together and how this shapes them. Although she is not speaking specifically about the co-evolution of the species, her theories do seem to provide support for a co-dependence between humans and dogs. In this book, she provides examples where this dance takes place, one of these, which I found particularly relevant considering the agility training background of many of our canine research participants, was the agility example. In this sport, both dog and human must respond to each other's cues and actions.

Using Haraways notion of "becoming with animals" Westerlaken and Gualeni include the animal as a participant in the ACI design process [128]. The knowledge that emerges from their work aligns with Haraways concept of *situated knowledges*, meaning "conversations from below, departing from partial, critical, and interpretive translations of possible worldviews that allow for unexpected openings and negotiations [46]."

Also particularly relevant to my research has been Haraway's framing of the symmetry and lack thereof in our dealings with animals: "The animals make demands on the humans and their technologies to precisely the same degree that the humans make demands on the animals. Otherwise, the cameras fall off and other bad things happen to waste everybody's time and resources. That part is "symmetrical," but the contents of the demands are not symmetrical at all. [47]"

This lack of symmetry can be seen in our efforts at communicating with animals, whether it is through the use of American Sign Language and KoKo, or through the usage of a keyboard for dogs. This work, the "dog at the keyboard project" was one of the first documented efforts aimed at symbolic dog-to-human communication [106]. In this research a modified toy keyboard provided dogs the means to make requests by pressing keys that produced sounds. The dogs were taught what each of the keys meant. Findings suggested that “dogs may be able to learn a conventional system of signs associated to specific objects and activities.” This is one of the few examples of improving agency in a dog’s life through the creation of a specific artifact.

2.3.2 Clever Hans Effect

No research involving animals can escape the shadow of the “Clever Hans” phenomenon, nor can any research involving dogs not include background into the unique abilities of canines that confound many computing experiments [28]. The “Clever Hans” effect is named for Wilhelm von Osten’s horse Hans who would pick up on subtle cues from his human to solve arithmetic problems [61, 95]. This effect is frequently referenced in research with animals and is a particularly challenging issue when the animal is a keen observer of humans like the dog. Dogs have been shown to discriminate emotional expressions on human faces which heightens the risk of unintentional cueing by the experimenter [84]. Dogs have also been proven to be excellent at following intentional cues from humans [49, 115] particularly when they deem the human to be reliable [116].

A frequent confound of laboratory experiments is a lack of proper accounting of canine olfaction capabilities as seen in Johnen, Heuwieser, & Fischer-Tenhagen [60]. Although the olfaction capabilities of the dog are known to outperform instruments, experiments have been confounded due to not properly accounting for the distance and concentration amount of scent that a dog is able to detect [38, 51]. Dogs are able to detect scent from over 62 meters away [21] and at volumes as low as 5.0 to 0.005 μL [19], and amounts as small as 0.2g [8]. Even if the experiment is not testing scent detection, dogs have used scent to identify activity trails of both humans and other dogs, which can provide a clue for determining which choices have been selected by other participants and where the experimenter and artifacts have been. Dogs use their nose to identify clues, to solve problems, and prefer it over using visual cues, which are the ones human experimenters are more apt to properly account for in the design of laboratory experiments [39].

2.4 Working Dog Research

Considering the range and number of occupations that dogs have, it is not surprising that beyond medical research on dogs, the majority of canine research has been focused on working dogs. Working dogs are primarily defined as canines with one or more specific skills that enable them to perform essential tasks for humans. Working dogs that assist humans with disabilities are called assistance dogs. Other working dog occupations include field work, such as search and rescue (SAR) or explosive-detection. The specific skill in working dogs is typically olfaction-based, and often requires high levels of performance and discrimination, for example, explosive-detection dogs can categorize explosives based on chemical characteristics, most notably between "stable" or "unstable" compounds [38]. The high demands on working dogs and the cost to train them have meant that the majority of working dog research centers on evaluating performance and predicting training regime outcomes.

2.4.0.1 Performance Evaluation & Outcome Predictions

Many attempts to improve working dog outcomes aim to predict a dog's suitability for an occupation before a costly training regimen is started. These assessments are based on behavior tests, lateralization tests ('handedness'), and surveys filled out by human caretakers [118, 108].

Recent work by Berns et al. used Functional MRI scans to predict successful assistance dog outcomes in dogs between 17 and 21 months of age [15]. They used anatomically defined regions-of-interest in the ventral caudate, amygdala, and visual cortex, to developed their classifier based on the dogs' outcomes. This classifier had a positive predictive value of 96% with 10% false positives.

The most successful prediction of working dog training outcomes and occupation success with dogs as young as 9 months have come from Slabbert et al. [111] His two-year longitudinal study was focused on determining the factors influencing the success of police dogs. This study involved behavior testing of dogs as young as eight weeks and determined that the most reliable predictions of adult police dog success came from a series of tests performed when the dogs were between eight weeks and 9 months of age.They were able to predict with 81.7% accuracy which dogs would be unsuccessful in police training and predicted with 91.7% which dogs would become successful police dogs. The living and training arrangements for the dogs in the study are not typical of those found in many large working dog organizations, specifically those in the United States, due to the numbers of dogs in their care. While this study is frequently cited in the working dog community, the results are difficult to replicate in many organizations because of their inability to scale. [110]

2.5 Modern HCI and Canine Cognition

According to Rogers, the second generation of HCI theory, the Modern generation, brings cognition out of the head and observation out of the laboratory with a focus on ethnographic field work and theoretical approaches such as Activity Theory [65], Actor–Network Theory [112], Situated Action [86], and Distributed Cognition [55]. We have seen a similar movement in the study of dogs. Canine Cognition research broke from the previous generation of Behaviorists and sought to bring about a deeper understanding of the thought processes of dogs [79]. Canine Cognition, like many of the frameworks from the Modern generation, also seeks to consider context and often has a focus on the flow of information, particularly information that is socially constructed, which makes Distributed Cognition (DCog) a particularly strong complement to this type of research. DCog's power in describing the flow of information in a cognitive system and the granularity that DCog provides is helpful when analysing complex systems involving both dogs and humans, which is why it has been one of my frequently used lenses throughout my research trajectory [45].

Another particularly helpful complement to Canine Cognition is the work of Greeno, Collins, and Resnick, in their summary of differing views of learning and cognition and how these can be applied to the classroom and curriculum [43]. One of these views in particular, the Situative/Pragmatist-Sociohistoric, perspective has significant relevance for canines due to the nature of social cognition in dogs [24, 48, 78]. As Greeno et al. state on the Situative/Pragmatist-Sociohistoric perspective, knowledge is distributed among "individuals, the tools, artifacts, and books that they use, and the communities and practices in which they participate," (p. 20) and prescribes a learning environment that is social in order to best support the learner. This social organization of the learning environment is key for canines as their learning process is highly social and a complement to the social nature of their cognition [33, 36, 96].

Actor–Network theory (ANT) is a lens well suited for research involving animals and computing [68]. This choice stems from ANT not privileging human actors, as both human and nonhuman elements are treated equally as actors [117]. While not created specifically for the purpose of understanding networks involving animals and humans, Latour's ANT does help researchers move beyond centering everything around a human [67]. Recent work by Westerlaken and Gualeni draws on ANT to create a conceptual framework [128]. The purpose of this framework is to aid designers who wish to move beyond anthropocentrism when creating computing interactions for dogs.

2.6 Contemporary HCI: Action Research & ACI

The third generation of HCI, Contemporary, is categorized by approaches that consider culture, ethics, and social consciousness. Action Research [52], Critical Theory like Feminist HCI [9], and Animal-Computer Interaction [72] are part of this period.

Action Research (AR) is a class of research methods and approaches for conducting research that seeks to generate workable solutions alongside community partners. AR has a point of view, as Greenwood and Levin state, "To commit to AR in these circumstances is to affirm solidarity with the oppressed and to declare an adversarial role toward the powers that be," [44], and does not ask the researcher to set aside their point of view or strive for objectivity. AR is inherently value-laden. Viewing my work through this lens prompted me to become a certified professional dog trainer and sit for the CPDT-KA exam, thus gaining a deeper understanding of my users and gaining a respect among the communities I work with. AR is built upon the work of the Pragmatists, in particular John Dewey, and argues that knowing is a process of continuous cycles of action and reflection [30]. These principles of AR made it an ideal framing device for my research with my working dog training collaborators to create transferable solutions. This process of inquiry in AR has shaded the manner in which my research has evolved, including my becoming a part of the working dog training organization as a puppy raiser.

2.7 Computing and Animals

While research in computing with animals has gone on longer than the popularization of the term Animal-Computer Interaction (ACI), this term used by Mancini served to create a descriptor for a type of computing research with animals. Mancini also provided a framework for considering the ethical challenges in computing research with animals. Much of the discussion in the ACI community reflects other HCI Contemporary theories and these lenses and frameworks provide a way for ACI researchers to unpack what is informing their designs and how to analyze the impact that these artifacts will have on the animals and the ways in which they could potentially be interpreted and used [18]. The turn to the wild provides researchers with a way to design, prototype, and implement technologies in situ [102]. Due to the nature of much computing with dogs research, in-the-wild studies are necessary in order to validate the prototypes. Dogs are highly contextual and by removing them from the environments where they live and work in order to test a device in the lab, it is difficult, if not impossible, to understand the impact that a prototype might have on their life and job without a high degree of ecological validity [82, 104].

Although the field of Animal–Computer Interaction (ACI) is relatively new, there is a body of previous work documenting interactions between animals and computing devices. Early examples include remote entertainment and training by Hu et al. [57] and Resner [99]. Research that uses ubiquitous computing for the well-being of animals in shelter settings has inspired my own work using wearable devices to increase the permanent adoption of shelter dogs [75].

2.7.1 Dogs and Wearable Computing

Computing research that involves wearable technology on dogs includes the harness-based FIDO system, as well as work by Savage and Wingrave [59, 107, 129]. The muzzle [39] and collar [91, 5] are also areas in which wearable technology has been integrated.

Although the majority of computing researchers designing wearables for dogs believe that by following the principles of user-centered design, user-specific challenges are addressed whether that user is a dog or a human [89], some ACI researchers have argued that this is not enough and that one must design “with, as opposed to for the dog and have called for a re-imagining of the design process when the user is a canine

[100]. Nonetheless, similar to HCI research with humans, there are an array of methods and lenses to use, and there is no single one that addresses every issue and is a universal fit for all research. When issues that are unique to canines are not fully addressed by HCI guidelines, wearable computing researchers like myself, have adapted them, which we can see in my canine friendly adaptation of Gemperle's wearability guidelines [41, 120]. This altering of the design guidelines to encompass canine specific issues is also seen in the Challenges of Wearable Computing for Working Dogs, which I derived from Starner's Challenges of Wearable Computing [123, 113, 114].

CHAPTER III

DESCRIPTIVE SYSTEMS FOR WORKING DOGS

Descriptive systems are those that allow dogs to describe aspects of their environment for a given task. In the present work, these descriptions take the form of discrete alerts. While these discrete alerts are chosen by humans, they do enable the dogs to convey messages they were previously unable to, and to communicate with a wider range of people who might not have experience reading dog body language or signals.

3.1 Wearable Alert System for Service Dogs

3.1.1 Summary

Our first Descriptive system is a wearable interface for mobility-assistance dogs. Mobility-assistance dogs are service dogs that assist people with impaired mobility, to request help for their owner [124]. Our first goal in this study was assessing the reliability of the interface and dog activation. Our second goal was to understand both system and dog training challenges. We improved 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 discussed with active assistance dog users the technical, social and canine considerations, of such systems.

3.1.2 Research questions

1. Can a wearable alert system be designed that is dog-activated?

2. Can a dog reliably activate a wearable alert system?

3. How can a wearable alert system be designed to be more inclusive of the ranges

of canine reach?

3.1.3 Motivation

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

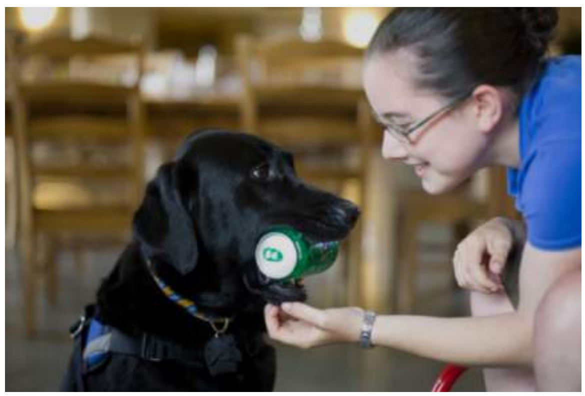

Figure 1: Mobility assistance service dog. Reprinted with permission from Canine Companions.

We present a system (Figure 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 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 an interface that triggers playback of a pre-recorded message. In the current prototype, the message says "My owner needs your attention, please follow me!"

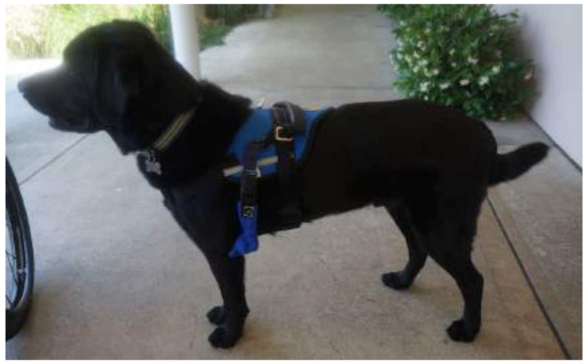

Figure 2: Service dog wearing one of the early prototypes. When tugged, the microcontroller on the harness plays an alert message. Reprinted with permission from Canine Companions.

3.1.4 Methods

3.1.4.1 Materials

The main pieces of equipment in the present study were four instrumented dog harnesses consisting of a tug interface and the associated electronics to produce an audio message when it was pulled. The tug interface consisted of either a Kong Wubba toy (Figure 3) or an equivalent braided fleece. We connected these interfaces to a flexible stretch resistor by Images Scientific, Inc., which acted as a sensor whose resistance changed when stretched (Figure 4).

Figure 3: Commercial Kong Wubba toy affordance.

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. The third and fourth components

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

Table 1: Subject demographics.

Subject	S1	S2	S3
Breed	Retriever	Border Collie	Border Collie
Training	Service	Nosework	Medical Alert
Sex	M	M	M
Age	7	7	6
Weight	31.75 Kg	21.3 kg	15 Kg

were a speaker and a 9V battery pack, respectively.

3.1.4.2 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 harness for the purposes of this experiment in order to avoid altering their training. However, partners of active service dogs were allowed to informally train the use of the harnesses at their own discretion and provide any feedback to improve our design.

3.1.4.3 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 signifier 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 interface to determine the optimal angle for the interface. 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.

Proof-of-concept Prototype

When asking service dog partners about using a harness like the first prototype they expressed concern that the visible electronic components could be intimidating to bystanders (Figure 5). If so, this aspect could limit the harness'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 harness 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 the dog's posture change when it was worn for extended periods of time.

Scenario-specific Prototype

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

Figure 5: Prototype 1 used a Julius K9 harness with electronics components mounted on the top.

seams of the harness to conceal and protect them (Figure 6). We also moved both the microcontroller and the battery to the right side of the harness to allow access to the handle. With these improvements, the harness 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 interface (left side), which caused unforeseen issues. For example, every time a dog would tug the interface, 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.

Figure 6: Prototype 2 with the opaque enclosure now placed on the side.

Canine Reachability

At this point, we began to reconsider the side placement altogether. One user suggested that a dog reaching a tug interface on 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 interface [120]. We tested seven locations and each dog's ability to reach them (Figure 7).

Figure 7: Seven on-body locations were tested; four 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 (Figure 8). Nonetheless, even with training, the side locations still exhibited a higher error rate than placements within sight.

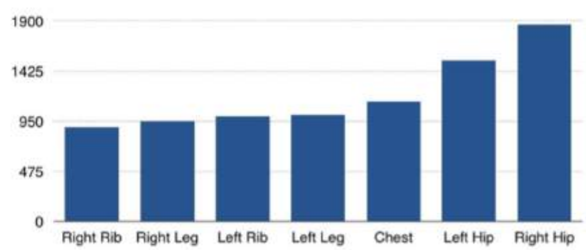

Figure 8: Canine Reachability Results. As seen above, with training, some side placements even achieved faster access times than some front placements.

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 interface because its location was unpredictable. Some dogs got around this issue by raising the tug signifier 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 [13]; 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.

Lightweight adaptable system

Due to the experimental nature of this prototype we reverted to using a Julius K9 dog harness 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 harness. To keep the location of the signifier consistent, we used a fabric tube to keep the interface in a predictable horizontal position, rather than dangling freely (Figure 9).

Figure 9: Prototype 3 being worn by one of the participants. This prototype has a fabric tube that holds the tug interface 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 harness 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 harness 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 interface 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 tug interface and tended to make grabbing it difficult. Surprisingly to us, when reaching unsuccessfully for the interface subject S1 would only manage to nudge the tug interface and, unintentionally, push it further into the tube rather than outwards.

To help correct for these issues, 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 harness. We also 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 (Figure 10). Every time the angle of the tug interface 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 1023. 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.

3.1.5 Findings

Following the performance metrics from previous experiments with wearable activation sensors as seen in Jackson et al. [59], we analyzed the videos and computed the following individual metrics of accuracy for both the sensor and the dog.

3.1.5.1 Performance metrics

We found it necessary to define specific types of accuracy to account for unforeseen cases. These cases included the dog performing the incorrect action on a given cue, activating the sensor more than once per cue, or unsuccessfully trying to reach the interface.

Cue Response Accuracy: describes how well the dog responded to a cue to interact with an interface.

Interface Detection Accuracy: describes how well the system was able to detect a correctly performed activation from a given interface.

Interface Reachability: describes how well a dog was able to reach or access a given interface. Because this metric can affect all others, we examined it in greater detail in a follow-up study [120].

Table 2: Definition of terms for each of the three performance metrics.

	Total (N)	Deletion	Substitution	Insertion
Cue Response Accuracy	Cues	Dog ignored cue	Dog performed incorrectly	Unrequested dog action
Interface Detection Accuracy	Interactions	False negative	Incorrect detection	False positive
Interface Reachability	Reach attempts	Unsuccessful reach		

Finally, we employ a global metric, the same used in Jackson et al. to quantify the effectiveness of the system in these experiments (overall success) [59]. Unlike Cue Response Accuracy (CRA), this last metric does not decrease with multiple successful activations per cue because this behavior would be beneficial in a real-life scenario.
$OS = \frac{A}{N}$ N = Handler intents (cues)
A = Successful Activations

Compared to our previous results, we were able to improve on all performance

Table 3: Tabulated results per dog for each performance metric. The tug interface results from this experiment are an improvement over the previous design.

Dog	Cue Response Accuracy	Interface Detection Accuracy	Interface Reachability	Overall Success
S1	91%	91%	82%	82%
S2	69%	92%	92%	100%
S3	90.1%	90.9%	100%	90%
Previous Total	83%	60% (and 2 FP/hr)	87%	84%
Current Total	4%	91% (and 0 FP/hr)	91%	91%

areas, specifically on Interface Detection Accuracy (Table 3). The marginal improvement on Cue Response Accuracy is expected considering that dog's understanding and obedience of the task was not affected directly by the harness. Nonetheless, we note that due to being distracted by the environment, S2 had a lower CRA 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.

3.1.6 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 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 interface 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 harness on a given day (Figure. 10).

In previous experiments, testing dogs of different sizes required instrumenting multiple harnesses. In some cases, this issue resulted in three duplicate harnesses

Figure 10: This prototype has two tug interfaces. Each interface consisted of a tug toy whose flaps were cut, sewn together and attached to a plastic clip..

being created and simultaneously maintained. For example, if our testing showed that a harness design required modifications, these modifications had to be duplicated for each dog 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 harness such that, if it had to be shortened, it could simply be folded onto itself and attached as usual (Figure. 11).

Figure 11: The folded strap mechanism was made to account for dogs of multiple sizes.

3.1.7 Conclusion

We have presented a series of prototype harnesses 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 share our reflections based on conversations with active service dog users with regards to technical, social and canine considerations, which would 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 interface at home without the need for a full harness. Some of the challenges to be addressed with this approach are the reliable activation of a interface 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.

3.2 Gesture-based Alert System for Working Dogs

This work relies on discrete gestures sensed from a collar-worn device to generate alerts [121]. This research was motivated by the desire to move away from a harness-based system and into a system that could utilize the equipment a dog was already wearing, a collar. By moving away from tug interfaces like those in our previous alert system work, we can also make the system safer by removing potential hindrances. In order for this system to be successful, discrete gestures that a dog can perform needed to be discovered, trained, and distinguished from their everyday activities [122].

3.2.1 Research questions

1. Are there abstract gestures that dogs can learn to perform reliably?

2. Can any of the gestures sensed from a collar-worn device be distinguished from everyday activity?

3.2.2 Motivation

This work follows the wearable activation interfaces used for the wearable alert system described previously. However, it is aimed at working dogs who might have existing harnesses or wear no harness at all. In these cases, a gesture-based collar-worn device can allow the same type of communication without requiring additional equipment overhead.

3.2.3 Methods

We examined a series of gestures to be used for communication. We examined recognition sensitivity based on laboratory examples of these gestures while propensity to false positives was evaluated with data recorded in an outdoor environment.

3.2.3.1 Gesture selection

We began by determining a set of seven requirements that could prevent a gesture from being used for these purposes (Figure 12)

1. Transferability across subjects: We should not rely on gestures that can only be performed by a single participant without modification and considered exceptional even among dogs of a given occupation.

2. High true positives (System sensitivity): The system must detect the gesture correctly each time it is performed.

3. Low false positives (System specificity): The system should minimize alerts when no gesture has occurred.

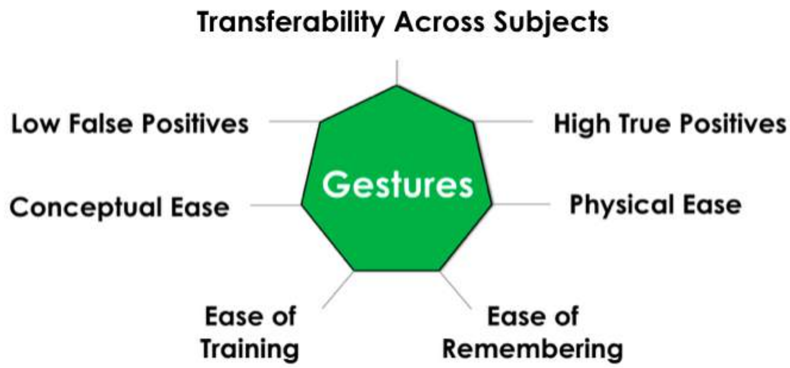

Figure 12: Criteria for ideal gestures. Addressing one aspect tended to affect others.

4. Conceptual ease: The gesture should be able to be performed within the bounds of a dog's working memory. For example, repeating a gesture an arbitrary number of times would be conceptually difficult due to the demands on working memory and would not meet this criterion.

5. Physical ease: The dog must be able to perform the gesture. For example, a back flip would not meet this criterion.

6. Ease of training: The gesture must be able to be trained.

7. Ease of remembering (Memorability): The dog must be able to remember the gesture after the training phase.

We then recruited two dogs, a convenience sample, out of a pool of nine trained dogs and recorded isolated examples of each gesture. These examples were used to estimate detections (true positive) and missed detections (false positives).

3.2.3.2 Protocol and participants

We now describe how we prompted the gestures we further examined with a dog having no previous experience performing gestures on cue.

To avoid training a dog to perform a gesture that would ultimately be undetectable from everyday movements, we first tried to "lure" them into performing each candidate gesture. Luring is a technique by which dogs follow a target object (e.g., treat or toy) to perform an action [7]. We ultimately realized that readings from lured actions were more representative of the trainer's luring movement than the dog's performance, and hence could not be used as a stand-in for the dog performing the gestures on his own. Still, luring was valuable for dog training, but we did not record these instances as gesture templates.

Instead, we had to ensure dogs could learn to offer these gestures after being given a visual or verbal cue. Our first participant had limited previous experience with wearable activation interfaces and would not offer actions like "reach left" or "reach right" spontaneously. Our second participant had experience with the gestures, but performed them in broad undirected ways when lacking a precise target. We realized that even though a gestural system no longer required a dedicated interface for each alert, it was still necessary to have a visual or tactile target while the dog was learning and until our recognizer could provide feedback upon successful completion.

Although we experimented with auditory feedback (throughout and upon completing a gesture), we discovered that using a simple harness-based two-target system was enough to obtain the precision we required. Once trained, the dog no longer required the harness.

The harness consisted of two bright colored targets on each side (Figure 13). I built the targets out of bright yellow 3.81 cm (1.5 in) diameter balls to make them easier for the dogs to see [80]. Originally, I used a dark target against a dark background (the harness) as a marker, but that was harder to locate as it did not provide enough visual contrast for the dogs [87].

Participants: For this study, I trained two dogs using positive reinforcement. One dog, a two-year-old retriever (S1) with assistance training, had no experience with wearable interfaces and was trained to use them exclusively for this experiment. A seven-year-old Border Collie (S2), had experience with wearable interfaces for more

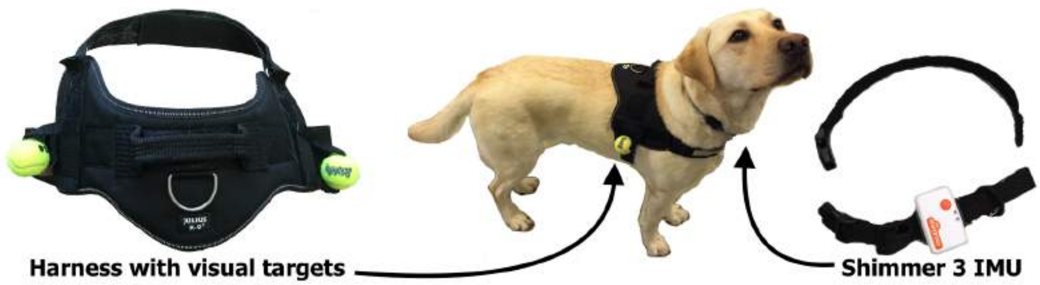

Figure 13: Participant wearing the instrumented Julius K9 harness and Shimmer 3 before a training session.

than three years.

Training protocol: When dogs attempted to perform a gesture they received a food reward (1-cm-sized treat) [53]. When they could perform the gesture correctly at least 65% of the times asked, the reinforcement schedule was decreased to one treat per successful completion [12]. Throughout this process I also provided immediate feedback with a click sound. For training spin and twirl I relied on luring at the early training stage before transitioning to a subtle hand signal and verbal cue.

Each training session lasted no more than 10 minutes. The average learning time for each gesture varied depending on the dog's prior training experience, but did not exceed more than 15 training sessions per gesture. Gestures were trained both off-leash and on-leash with the least experienced dog. The most experienced dog was trained off-leash but showed no observable difference performing the gestures on-leash as long as the leash was long enough to avoid interference.

As a result of his experience, we obtained the necessary gesture performance from S2 after two practice sessions, and by using more pronounced hand signals to illustrate the movement for the spin and twirl gestures. Participant S1 was trained intermittently, for almost two months, until he could perform the gestures from a single verbal or visual cue. No food, sensory, or water deprivation was used for training, nor during the experiment.

Table 4: Summarized results for each data set. Some dogs offered gestures more than four times.

Dataset	Minutes	Dog	Use	Events	False Pos	FP/hr	Precision	TP	Recall	Accuracy
Dataset 1	50	S1	Training	48	1 (left)	1.2	80%	4/4	100%	75%
Dataset 2	25	S2	Training	47	0	0	100%	4/4	100%	100%
Dataset 3	25	S2	Training	32	0	0	100%	5/5	100%	100%
Dataset 4	25	S1	Testing	37	0	0	100%	6/6	100%	100%
Dataset 5	25	S2	Testing	6	0	0	100%	4/4	100%	100%
Everyday	305	S1	Testing	50	2 (spin, right)	0.4				
Everyday	305	S2	Testing	18	0	0				

3.2.3.3 System and equipment

In addition to the two-target dog harness used for training, the main piece of equipment used for this study was a commercially available inertial sensor, the Shimmer 3, by Shimmer Sensing Inc. This unit consists of a 9-axis sensor, including three axes of accelerometer, gyroscope and magnetometer. The sampling frequency was set to 51.2 Hz.

We selected the Shimmer 3 due to its light weight and small size (51 mm x 34 mm x 14 mm) compared to sensors with similar capabilities. Considerations of weight are extremely important because heavy objects might obstruct the intended movements. The weight of 28.3 grams, is significantly below the maximum weight guideline (4% body weight) for wearables in Animal–Computer Interaction [130]. Finally, we used a two-pocket harness to place a mobile phone for longer-term wireless recording of everyday movements such that the resulting data matched our target scenario more than storing it locally.

3.2.4 Findings

We performed the same test used for tuning on each of the four remaining untrained sets. That is, there was a single recognizer applied to data from both dogs (the threshold was not adjusted for each dog). Testing data consisted of the two remaining interval datasets for true positives and two tests on five hour datasets containing everyday movements (Table 4).

3.2.5 Discussion

The results of our experiment were very encouraging. There were no substitutions between any of the four gestures. Similarly, for all the gestures performed as part of the interval datasets there were no deletions. Part of the reason is that while tuning our parameters, extra emphasis was placed on correct identification because without it, no comparisons to false positives would be possible. In other words, even though our sample size of gestures performed (23) is not sufficient to justify broader conclusions, it is a bare minimum to provide a reference for comparing gestures against each other.

Most of the false positives detected for each gesture occurred due to the spontaneous repetition of the gesture requested (for left and right reach). For spin and twirl, we expected some false positives to occur because the dogs did perform an equivalent motion while playing. From this experience we found it useful to make the following distinction.

3.2.5.1

Types of false positives We have found it useful to make a distinction between two types of false positives, *classificatory* and *behavioral*. The first type are cases where $gesture_i$ looks likes $gesture_j$ to the identification algorithm. The second type refers to cases where one gesture turns out to be a behavior present during daily living. For example, it might be that certain subjects perform a gesture spontaneously before lying down.

Behavioral false positives cannot be eliminated except by redefining the gesture in a more specific way. That is, ideally behavioral false positives can be redefined so that they can be distinguished from their gestural counterparts. The behavioral false positives can be estimated by the human eye while classificatory ones depend on the classifier.

3.2.6 Limitations

One of our key considerations for gesture selection was transferability and not generalizability. We define transferability as being able to create gestures that would work for our subjects and with adjustments, based on knowledge of another dog's needs and their context, could potentially be performed by other dogs. This has caused our work to endure some criticism as it not being as broadly applicable and useful to the wider community of working dog handlers. We do believe that our work is transferable and stand by this direction since with a species as diverse as dogs, it is a more suitable route. We are also aware of the limitations with providing lessons on transferability and ease of training given our limited participant pool and their training experience being largely derived from working with one dog trainer.

3.2.7 Conclusions

The methodology we have presented was suitable for analyzing and comparing gestures for further analysis. From our results, we have been able to understand the constraints and requirements of minimizing false positives. We also solved some practical problems in this area. We also observed that it is possible for dogs to perform gestures on leash without significantly affecting recognition.

Finally, we found four gestures that could be concretely defined, trained, and recognized in addition to discovering a novel way to train them. These gestures were recognized with 75-100% accuracy and their false positive rate averaged to less than one per hour.

3.3 Conclusion

The two prototype systems described in this chapter provide support for my hypothesis that wearable systems can create short-term interactions for communication a specific message. Both of these systems are an example of *Descriptive* interactions and allow dogs to send a specific message to humans.

CHAPTER IV

DIAGNOSTIC SYSTEMS FOR DOGS

Diagnostic systems rely on passive monitoring technologies that enable us to understand long-term activities and well-being of dogs. This understanding enables humans to gain a broader picture of their dog's needs and assess whether they are meeting them. This chapter contains two studies. The first, uses a wearable activity monitor to examine the impact that an increase in information can have on adoption returns and the perceived bond between adopter and an adopted dog [4]. The second section features a pilot study in which these same wearable activity monitors were used to look at rest habits of dogs in service dog 'advanced training' [6].

4.1 Increasing the Permanent Adoption of Shelter Dogs

We present the results of an eight-week pilot study with 55 dogs investigating whether using wearable activity monitors and a companion smartphone application can reduce returns of newly adopted dogs and increase the perceived strength of bonds between newly adopted dogs from the Humane Society of Silicon Valley and their adopters [4]. Through this pilot study, we developed guidelines for future research and discovered promising results indicating that providing dog activity data to adopters through the use of a smartphone application could yield reduced rates of re-relinquishment. Additionally, respondents indicated that they felt using the smartphone application helped them to better meet the activity needs of their dog and increased the bond between themselves and their newly adopted dog.

4.1.1 Research Questions

1. Does having more information about the activity habits of a dog prior to adoption facilitate better match-making and fewer returns?

2. Does having information provided throughout the day about a newly adopted dog help facilitate a bond with the dog?

3. Does the presentation of a dog's activities, being able to see if they meet the recommended amount of activity, impact an adopter's behavior?

The bond will be measured as it is perceived by the adopters. The impact on the adopter's behavior and bond measurement will be obtained from self-reported surveys.

4.1.2 Motivation

There are an estimated 4 million dogs relinquished to shelters each year [92]. The causes for relinquishment vary, and even without behavioral problems, almost half of all relinquished dogs are euthanized [70]. The load on shelters is exacerbated by the re-relinquishment, the return of newly adopted dogs back to the shelter, which Patronek et al. found to occur at the rate of 18.8 % [94]. Numerous studies have established links between social and economic factors of the owners, in addition to the (real or perceived) issues of the dog as the cause of this re-relinquishment. In the present study, we focus on addressing the problem of re-relinquishment among dogs in shelters in the United States.

Informally, the strength of the bond formed between a dog and adopter contributes to increasing the chance of a permanent adoption. The amount of time spent together, and the quality of interactions between adopter and dog, are crucial to the bond being formed. Additionally, there is evidence that the framing of quantimetric health information, such as data from wearable activity monitors, can cause human behavior

Figure 14: Dog wearing the Whistle Activity Monitor while in his room at HSSV.

change [23]. We hypothesised that knowing the dog's activity throughout the day, even when the adopter was not nearby, could have the potential to increase the speed of formation and strength of that bond.

One of the goals of this experiment is to better understand the role mobile technology can have on how adopters perceive the growing bond with their dog. Additionally, if the owner is aware of a low activity level for the day or week are they are more likely to ensure their dog gets the recommended amount? These levels have been correlated in existing literature with a decrease in behavior issues, which is a major cause of re-relinquishment [88]. Our hypothesis was based on known factors listed in the literature as associated with decreasing adoption returns, such as time spent with the human, and reducing behavior issues.

We aimed to test whether mobile technology, in the form of a wearable activity monitor and a companion mobile application, could be used to study the presentation and perception of this information in a way that reduces returns. For example, even though remotely checking in on a dog does not replace physical proximity, it can provide better awareness of what the dog's day is like when they are not together, as well as serve as motivation to spend more time together. This increase in time together is one way in which the bond between human and dog can be strengthened, but there are innumerable other ways in which mobile technology might help strengthen the perceived bond. By conducting this research in the wild, we also sought to contribute to our community a set of guidelines for future research, helping to pave the way for more interventions that utilize computing technologies and approaches uniting animal behavior and veterinary practitioners with computer scientists and user experience designers.

4.1.3 Methods & Procedure

To test our hypothesis, we conducted an 8-week pilot study. For this study we partnered with the Humane Society of Silicon Valley (HSSV). HSSV, established in 1929, has facilitated more than 500,000 adoptions and is located in Milpitas, California [90]. Whistle Labs, Inc. provided the primary sensing technology we deployed in this experiment, a commercially available activity monitor for dogs with a companion smartphone application (Figure 14). Whistle recommends their device for dogs over 9 lbs (4.08 kg), which was a selection criterion for our study.

Table 5: Participant details. Four dogs were removed due to health, safety, or foster reasons

Participants	**Control**	**Experiment**
Total Number of Dogs	30	25
Removed	1	3
Adopted	25	16
Trial Adoptions	1	2

At the commencement of this pilot study, there were 11 adoptable dogs suitable for wearing a Whistle Activity Monitor. They were randomly divided into two groups, 6 in the experiment and 5 in the control group. As new dogs that were eligible to participate in the study became available for adoption, they were alternately added into the experiment and control groups as determined by HSSV staff. During the duration of this study, 30 control and 25 experiment dogs participated. Four dogs were removed from the study due to health concerns, relocation to foster care, or

Figure 15: Whistle Activity Monitor information printed outside of an HSSV dog's room

safety concerns due to chewing of the Whistle device (Table 5). A total of 41 of the 55 dogs were adopted during the duration of the study.

All dogs in the experiment group wore a Whistle Activity Monitor on their collar. The dogs wore the monitor continuously, with the only exception being an hour-long break once a week for charging. Information from the monitor about the dog's activity was displayed in a custom-built simulated app view for this study on the HSSV website. This view was designed to give a snapshot of the dog's activity levels over the past few days, similar to the Whistle smartphone application. It showed an indicator of the number of minutes the dog was active throughout the day, as well as a bar graph showing the exact periods of time the dog was active vs. resting. The 72 hour averages of this information were printed and displayed outside each dog's room at HSSV (Figure 15). During an adoption counseling session, the dog's profile on the Whistle mobile application was presented on an Apple iPod Touch and information about the activity and rest levels of a dog were discussed with the prospective adopter.

When a dog in the experiment group was adopted, the adopters had the opportunity to participate in the bonding study. Regardless of their participation in the study, the adopter was allowed to keep the Whistle Activity Monitor and was added as an owner of the dog in the Whistle mobile application by the adoption counselor.

Table 6: Experiment Groups.

Categories	Experiment Group
Adopted (including trial adoptions)	18
Consented to be Surveyed	12
One Week Surveys Received	6
One Month Surveys Received	5

During this eight-week long pilot study conducted at HSSV, 18 dogs in the experiment group (those wearing the Whistle Activity Monitors) were adopted. Twelve of these adopters consented to be surveyed (Table 6). We subsequently surveyed the adopters at one week and one month after the adoption about their experiences with using the technology and how it affected their experiences with their newly adopted dog.

HSSV obtained consent at the time of adoption, and Whistle Labs sent the surveys electronically. As stated earlier, all adopters of dogs in the experiment group were able to keep the Whistle Activity Monitor regardless of their survey participation.

The timing of the survey after one week and one month of adoption was based on research by Modelli et al., who found that of adopted shelter dogs that are returned, 40.7% were returned within one week [83]. Returns after one week were staggered, but the mean period was found to be 33.8 days. Over half of all adopters who returned the dog within a week cited the dog's behavioral problems as the reason for the return.

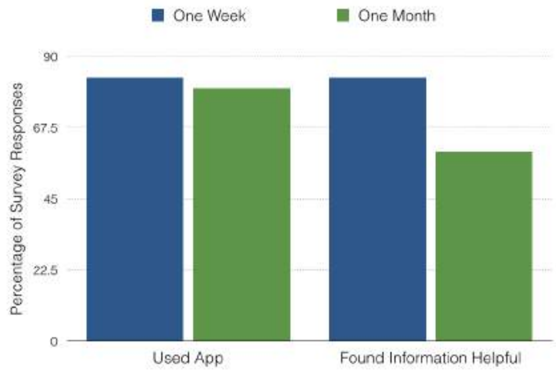

Figure 16: Comparison of One Week & One Month Survey Responses

4.1.4 Findings & Discussion

The rate of re-relinquishment for the experiment group was 6.25% (Table 7). We also computed the re-relinquishment rate of 8.3%, for owners who consented to be surveyed, in case the surveying influenced their decision. The rate of re-relinquishment for the control group was 12%. For comparison, the average rate of re-relinquishment as found by Patronek et al. was 18.8 % [94]. The rate of re-relinquishment of the control group is consistent with HSSV's average rate as reported by staff. Examining the correlation between respondents who reported using the app and the overall re-relinquishment rates would be insightful, however the group of survey respondents who supplied information about their usage of the app is not large enough to permit this analysis. Among our survey respondents, 83.3 % of respondents used the app during the first week, and 80 % were still using the app one month later. In addition, 67 % of the one-week respondents and 60 % of the one month respondents indicated that they found the information provided in the application helpful in understanding and bonding with their dog (Table 16). Although the window for re-relinquishment was 90 days and extended beyond the duration of the study, we did not have permission to contact adopters 90 days post adoption. Insights into usage of the app beyond a month would be very useful to have, especially as there are multiple dogs wearing Whistle activity monitor in the app community that have published meeting

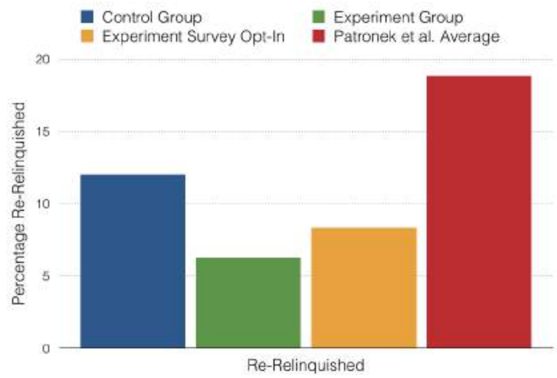

Figure 17: Re-Relinquishment Comparison. Experiment totals are not inclusive of trial adoptions.

their activity goals for well over 100 days. During both the one week and one month survey we asked several open-ended questions regarding the experience of using the system.

Table 7: Overall results for each adoption group

Group	Relinquished	Percentages
1. Control	3/25	12%
2. Experiment Total	1/16	6.25%
3. Experiment Survey Participants	1/12	8.33%

Responses from adopters include:

- “It’s kept me on track with her exercise and her habits.” (S3)
- “Besides being fun to check out, it gives a great picture of activity/rest periods. It’s also very helpful to see how much activity is going on when Sam’s (name changed to protect privacy) home alone.” (S4)
- “Being able to set goals reminds me to keep him active and take him on walks, which only helps the bonding time with my dog.” (S1)
- “It’s a great way to keep dogs active as well as see what they’re up to when you’re at work.“ (S1) ...

In addition, 83.3 % of respondents indicated that they checked the application multiple times a day. Adopters also reported that they increased the time spent with their new dog and also increased their dog’s activity level based on information that was provided to them from the activity monitor. As shown in several studies, having an appropriate amount of exercise can reduce problematic behaviors in dogs which are a common reason cited for re-relinquishment [88]. We hypothesize that the (reported and actual) change in the habits of both the adopters and dogs in this study may be due to the adopter reflecting on the information presented [54]. The survey responses illustrate why using the system may be beneficial. We did not have permission to interview the adopters, nor view their app use, but feel that future studies should incorporate these aspects in order to gain a deeper understanding of how the system was used in building the bond with their dog. Comparing what features they actually used and how they used the system would be highly informative, especially when compared against their self-reported usage and value they indicated that they placed in specific features.

4.1.5 Limitations

The re-relinquishment rate is higher among those in the experiment sub-group that consented to be surveyed than the experiment group as a whole, although when compared with the control group, both are lower. However, due to the small size of the groups, this difference in re-relinquishment rate is not significant. We do acknowledge that there could be a selection bias with our re-relinquishment rates due to who adopted from the experiment group (these adopters had more information about the activity levels of the dogs prior to their adoption), who consented to be surveyed as part of the bonding study, and the location from whence the dogs were adopted, namely, the Humane Society Silicon Valley. Previous studies have linked several factors such as education and household income, that are higher than the national average in the demographics of Silicon Valley, to lower rates of re-relinquishment [93]. Future work should address this potential confound by conducting the study at multiple locations with more diverse demographics. In addition there are limitations on the activity reported in the app often being more reflective of the caretaking habits of the staff or adopter than of the dog's actual activity level. This however, may be less relevant in our study as the app still provided a way to monitor how much exercise the dog was currently getting and see the history of so adopters could maintain the exercise level in their new home. Despite these limitations, the results from our study are promising and do merit a larger follow-up study with multiple locations. The results from our study suggest that wearable activity monitors and their companion mobile applications could have the potential to reduce the rate of re-relinquishment by providing better information about the dog at the time of adoption, promoting healthy dog care habits, and by potentially accelerating the creation of a strong bond between the adopters and their new dog.

4.1.6 Conclusions

Our current results are encouraging, and despite the small sample size, they provide multiple insights. Through this study we were able to test our hypothesis in a real-world environment, providing high ecological validity. By conducting this study in a working animal shelter, and surveying adopters, we were able to learn not only about whether this tool could be helpful for new adopters and shelters in preventing re-relinquishment, but also about what some of the challenges would be in implementing such a system on a larger scale.

In order to help future researchers in the community navigate the aforementioned challenges we created, using our perspective as action researchers, a set of guidelines for conducting research with computing technologies in animal shelters:

1. Practitioners from the domain should be involved in the design of the study.

2. The study should be designed to minimally impact daily shelter operations and ideally not require shelter personnel to maintain the technology.

3. Data collection from the animals must be non-aversive, pain-free, and not taxing emotionally or physically.

4. The study should not negatively impact the adoption availability or desirability of any animal in the shelter, including those not participating in the study.

By integrating these guidelines into future studies, challenges such as a lack of Wi-Fi in kennels/rooms, or interference with wireless data transfers, could be identified early and planned for. Due to the reliance that many mobile and wearable technologies have on wireless connectivity, troubleshooting such issues, and understanding the IT structure on-site before the data collection begins, is imperative. The majority of concerns typically revolve around the burdens placed on staff to help run the experiment and maintain animal welfare. Technology support from the research team is essential.

Our findings suggest that humans change their behavior in monitoring their dog similarly to the way framing personal health information affects behavior and health change [23]. In addition, by being able to remotely view the activity of their dog, they were able to feel more connected to the dog which could have contributed to the lower than average rate of re-relinquishment. Whether these benefits continue alongside usage of the app, or beyond usage of the system altogether would need further study. Given the number of Whistle users that continue to use the product well beyond six months, reaching their daily activity goal for a year, our hypothesis is that there must be a perceived continuous benefit to using such systems.

4.2 Restfulness and Dog Training Outcomes

In the summer of 2014, we conducted a pilot study on the use of the Whistle Activity Monitor in the kennel environment at two Canine Companions for Independence training centers [6]. Our goal with this study was to understand the relationship between levels of activity in the evening, lack of rest, and training outcomes. Through this study we gained a better understanding of both the rest habits of the dogs and the challenges of deploying wearable technologies in the field.

4.2.0.1 Canine Companions for Independence

Canine Companions for Independence (CCI) is the oldest and largest provider of assistance dogs in the United States. They provide dogs in four categories: service dogs for people with physical disabilities; hearing dogs for people with hearing impairments; skilled companion dogs for children or adults who may not be able to live independently; and facility dogs who work with a therapist or teacher.

Figure 18: A Whistle Activity Monitor being placed on a dog's collar

4.2.1 Research Question

Is there a relationship between the amount of nightly rest (inactivity in the evening) a dog receives during Advanced Training and the rate of graduation?

4.2.2 Motivation

While there is limited information on the role sleep plays for working dogs, there is some research on sleep in the domestic dog [1]. The hypothesis of our collaborator was that dogs who are more stressed are more likely to move around and have a restless evening than dogs who are adjusting well to training. These more stressed dogs in turn will be more likely to fail their training program, which Canine Companions classifies as being "released."

4.2.3 Methods

For this study, a total of 45 dogs, all labrador retrievers, golden retrievers, or crosses of these two breeds, at two different CCI training centers were outfitted with Whistle Activity Monitors 18, a commercially available wearable sensor and monitored through a portion of advanced training. This device contains a Freescale MK60DN512 microprocessor, the TI CC2564 bluetooth chip, the Atheros AR4100(p) WiFi chip and the STMicroelectronics LIS3DH accelerometer. Our sampling rate was 50hz.

To investigate possible differences in activity between dogs that graduated and dogs that were released, measurements from the Whistle Activity Monitor were split by time of acquisition: day (7 AM - 7 PM) or night (7 PM - 7 AM). These hours were selected based on the schedule established in the kennels. 7 PM was when the dogs would begin their evening rest, and 7 AM was the time their day would begin.

The number of minutes of activity and inactivity as defined by the Whistle Activity Monitor were then calculated for each time period.

We considered the dog to be inactive when the absolute value of the accelerations after they have been high pass filtered with a cut-off frequency of 1 Hz are less than 5/16 of the acceleration due to gravity in all three directions for the entirety of the minute. Video analysis was done to confirm that these calculations of rest were accurate.

4.2.4 Findings

The number of minutes of inactivity at night for dogs who were released (mean = 581 minutes) was found to be significantly different ($P < 0.05$) from the dogs that graduated (mean = 607 minutes) as shown in Figure 19. Dogs that were more restful had a lower rate of failure in the training program.

None of the other calculated variables, such as activity level or activity type, were found to be significantly different between the two groups. However, when this analysis was repeated while controlling for the dog's location, the difference in minutes of nighttime inactivity was not found to be significant for both training centers.

The results from this study emphasize the possible correlation of working dogs performance with restfulness at night, when the dogs are away from trainers and otherwise unobserved.

4.2.5 Discussion

This study suggests that quantitative information from wearable devices like the Whistle Activity Monitor may be useful in tailoring the training environment and

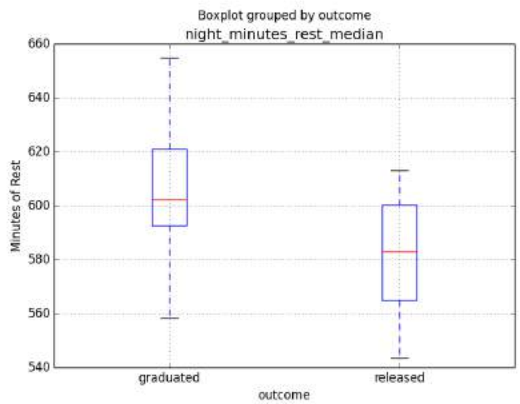

Figure 19: Median minutes of rest

demonstrates the possibilities of utilizing quantitative measurements from wearable activity monitors to assist in the care and training of working dogs.

4.2.6 Limitations

Only dogs with at least 14 full days of data were considered in the following analysis, resulting in a total of 22 dogs from Training Center 1, of which 20 successfully graduated, and 17 dogs from Training Center 2, of which 12 graduated the program.

4.2.7 Conclusion and Contribution

The work with the CCI training centers showed a statistically significant correlation between higher at night and the dogs' training outcomes. The results were presented at the 2015 International Working Dog Conference and practitioner attendees found the contribution to be useful in their practice.

4.3 Conclusion

Diagnostic interactions allow humans to understand canine actions on a broader scale. In this chapter we saw examples of two such systems. The first system used information provided by the wearable device to increase the permanent adoption of shelter dogs and the perceived bond between adopter and dog. The second study showed how wearable technology could be to inform caretakers in a working dog environment how dogs were resting at night in their kennels. This study found that higher inactivity at night correlated with an increased rate of training success.

CHAPTER V

DIRECTIVE SYSTEMS FOR CANINE–HUMAN COLLABORATION

We explore how wearable computing systems can enable canine–human collaborations through two studies. The first study in this chapter describes a system designed for law enforcement officers (both human and canine). This system provides a platform for the canines to communicate with other officers beyond their handler. The system improves communication among all officers, even across municipalities [3]. The second system described in this chapter is PAWS: Puppy Accelerometer Data for Working dog Suitability. The PAWS system uses the accelerometer data from the dogs to adjust their training environment. While this collaboration is not as active as the one detailed in the law enforcement system in this chapter, it is an example of canine data being used as part of a decision making process involving multiple collaborators.

5.1 Mobile Collaboration for Explosive Detection Teams

We designed a communication system for law enforcement officers to use when conducting explosive detection searches with multiple agencies. Dogs trained in explosive detection work alongside human handlers to form a K9 team which is an integral part of these searches. Human officers in K9 teams have a strong bond and communication with these dogs, but noisy locations, long distances, and crowded spaces present challenges. In addition, other officers assigned as backup often lack the experience to read the cues from the canine, which hinders the speed and effectiveness of the team. Coordinating a search with teams from different municipalities presents challenges due to a lack of standard collaboration tools. Getting the right information as quickly as possible saves lives, whether this information is about the areas that have been searched or the location of an explosive device. We hope that in addition to increasing public safety, our system will make working conditions safer for law enforcement officers and their canines.

5.1.1 Research Questions

1. Is it possible to integrate data from canine officers into a mobile app?

2. What are the collaboration tools that matter most to officers?

3. What platforms should a collaborative system for officers be built upon?

5.1.2 Motivation

Law enforcement is an integral part of our society, yet HCI research that supports law enforcement is under-explored. There is even less research involving police working dog teams. The majority of working dogs in police and military K9 occupations are trained to detect explosive devices [20]. Although instruments designed to detect explosive devices are available, the detector dog is still the "fastest, most versatile, reliable real-time explosive detection device available" [38]. A K9 team is made up of one human handler and one dog trained to detect a specific substance or detain suspects. In scenarios that involve special events (e.g. road race), are time-sensitive (e.g. an emergency), or cover a large area, multiple K9 teams, often from different municipalities, are commonly deployed. These municipalities are often different from those of other K9 units, other officers securing the perimeter, or officers in the Explosive Ordnance Disposal (EOD) unit. Issues with cross-municipality communication are exacerbated by a lack of both a shared secure radio channel and access to a common mapping software. Our goal is to create a system that improves communication between agencies, K9 teams, officers securing the perimeter, officers providing cover, and EOD units.

The impetus for this research, which began in early 2014, came from the social climate around law enforcement challenges and the technical solutions proposed by policy makers and the community at large [40]. As an HCI and action researcher specifically, I felt compelled to better understand these challenges. While I have not addressed all of them, I believe that what I learned and subsequently developed, is a good initial step in incorporating tools from HCI and Action Research to the design of law enforcement systems.

5.1.3 Methods

Our goal was to design a system that would address the unique challenges of cross-municipal explosive detection searches. To this end we largely followed the design process from Contextual Design as well leveraged insights from Distributed Cognition for Teamwork [17, 37]. To guide our understanding of the current officer work process during a search and to help us discover breakdowns, we chose to use the lens of Distributed Cognition [55] coupled with our AR framing. Distributed Cognition is particularly helpful for exposing system-workings at a level that would have design implications [103]. Additionally, we used thick descriptions as described by Crabtree for understanding collaborative work [26] in our analysis of our observations of the officers.

Following the design process from Contextual Design, we began with *Contextual Inquiry* followed by *Work Modeling*. During the Work Modeling phase we used Distributed Cognition to generate models representing the work of the officers. During *Consolidation*, we created tabular representations of the system that were inspired by DiCoT and used these to generate requirements for our system. We merged the *Work Redesign* and *User Environment Design* phases and moved to prototyping and testing with our participants as early as possible in order to accommodate for multiple iterations of our system based on their feedback.

Table 8: Composition of officer participation in this research

Officer Engagement	Number
Observed	25
Interviewed	4
Feedback	2

5.1.3.1 Participants

For this study we observed 25 officers, interviewed four and obtained system design feedback from two (Table 8).

Participants were recruited based on geographic proximity starting from the local campus department and extending to the county-level. The four participants interviewed included both campus-level and county-level officers (Table 9). These four officers formed our group of community collaborators which we worked closely with throughout the design process.

5.1.3.2 Contextual Inquiry

We began the Contextual Inquiry phase by speaking with officers from multiple jurisdictions; these included the Campus Police Department (CPD), two municipal police departments, and two county deputies. The conversations focused on understanding their current work practices and challenges. In addition to the conversations, we also observed 25 K9 explosive detection teams training from multiple counties and municipal police departments. Training sessions which simulate various search scenarios were the closest environment we had to observe the officers at work during a "real search." The searches we observed were conducted both off and on-leash. We noticed communication breakdowns in both scenarios. These breakdowns have multiple causes, although they can largely be attributed to a misread or missed alert from the dog. While an experienced handler is typically very adept at recognizing these alerts, the same cannot be said of backup officers with less experience. Even

Table 9: Interviewed participants by jurisdiction and occupation.

Participant	**Jurisdiction**	**K9 Handler**
P1	Campus	Yes
P2	Campus	Yes
P3	County	No
P4	County	Yes

experienced handlers can have difficulty seeing and hearing alerts in dark and noisy environments. The officers also expressed frustration at having access to new technologies, namely, Google Glass, but being unable to effectively integrate them into their practice [71]. The purchase of Google Glass by their department was to explore the usage of a head-mounted device that offered largely hands-free interaction. Google Glass seemed promising to their superiors, but was unused by the officers reportedly due to a lack of suitable applications.

Following the observations, we conducted a series of interviews with four officers. Three of the officers are the human handler of a K9 team (P1, P2, & P4), one of the officers serves in a leadership position (P1), and another officer serves as backup for K9 teams (P3). Two of these officers are from the Campus Police Department (P1 and P2) and two are from a county in another state (P3 and P4). Two of these interviews occurred in person at the workplace of the officers and were accompanied by additional observations of their practice (P1 and P2). All observations occurred in the United States and all officers interviewed were also based in the United States. While we saw similar challenges across localities, we recognize that these might not be the case outside, or even in all jurisdictions within, the United States.

5.1.3.3 Distributed Cognition

A key issue that the officers mentioned, which we also observed, were the challenges around communication across agencies and municipalities. Because each team, as well as the officers supporting the perimeter, can come from a different jurisdiction,

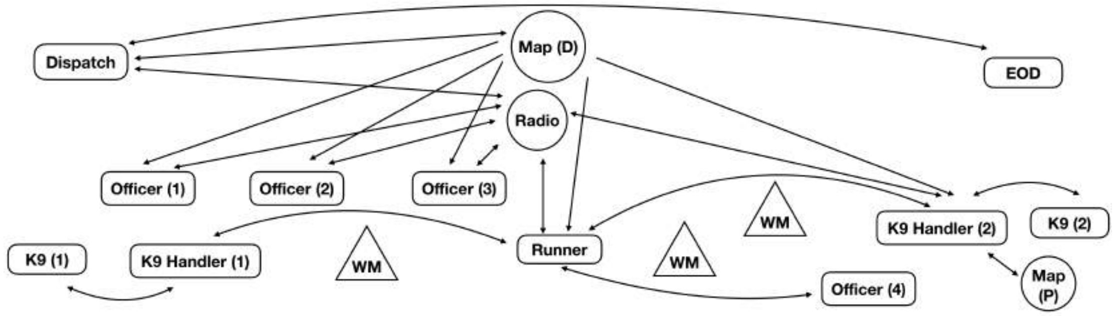

Figure 20: Graphical representation of representational states and processes during a cross-municipal explosive detection search event. Agents are circular. Triangles represent memory. Arrows represent processing and the flow of information.

there is no common tool that allows for live updating of search areas. Even within the same municipality, the map that displays positions of the teams can only be updated by the dispatcher and is displayed on a laptop computer. Because of this limitation, the mapping tool is underused and officers have to rely on other tools and personnel to communicate. The coordination process we observed and that was described by the officers was complicated and on occasion involved "runners". *Runners* are officers tasked with running between K9 teams and backup officers to update their information. Our Distributed Cognition diagram (Figure 20) is a result of the analysis of a cross-municipal explosive detection search event involving two K9 teams (each from different municipalities), one officer acting as a runner, with four officers setting the perimeter (three from the same municipality). This diagram does not account for aviation support, which is commonly used in well-funded departments to check the position of the officers setting the perimeter, the K9 teams, and update Dispatch, the central public safety communications coordination center.

Dispatch provides information to the officers setting the perimeter over the radio or through the mapping and call software that is on their department supplied laptops. These laptops remain in a mount inside their vehicles. Only Dispatch can update the information displayed in this mapping and call software which is abbreviated on the diagram as Map (D). Officers can communicate with Dispatch and with each other through the radio if they share a channel in common or a preexisting mutual aid channel. Officers without this access to Dispatch use their phones to call Dispatch. In the diagram, Officers 1-3 have access to both Map (D) and radio communication, Officer (4) not being from the same municipality, has access to information through a Runner. The Runner has access to radio communication and Map (D) and is responsible for communicating with other personnel who do not have access to these tools. This communication is commonly done by running to each location and verbally relaying the information or updating a paper map, depicted on the diagram as Map (P). K9 Handler (2) has access to the radio and Map (D) but needs to communicate to the other K9 handler through the Runner. K9 Handler (1) must use the Runner to maintain communication with the other officers. Both canine members of the K9 team can only communicate with their handlers. Communication with the Explosive Ordnance Disposal (EOD) team is done through Dispatch.

The diagram was helpful in providing us a way to visualize the breakdowns, as well as the demands on working memory (WM). Distributed Cognition made it clearer what needed to be fixed and served as framework that guided our design for a common tool.

Without a common tool, particularly one that was mobile, there are delays in communication. To alleviate these issues, phone calls and communication apps like those for text messaging, annotated paper maps distributed by runners, and aviation support confirming positioning through helicopter flight have all been used. The primary concern of the K9 handlers is that these communication issues cause frequent stops that impact the dog's ability to search and work. This is a particularly pressing issue in hot climates where the work time is already shorter due to the heat.

Our focus was on reducing communication errors, improving the time to response of K9 signals, and addressing the need for a mobile map that every team member was able to access and update.

5.1.3.4 System Design Requirements

After the observations and interviews, we discovered alongside our collaborators, key requirements for our system design. In particular, the system must allow the officers to perform these tasks:

- Receive notifications of important events from scent detection events
- View details about those events
- Annotate a map that all officers are able to view and also annotate
- View an updated map without needing to refresh and support displaying photos from the scene
- View the position of all users of the app, backup or K9 teams on a map

In addition the system should:

- Be accessible to a variety of municipalities and not require special hardware to deploy
- Be low-cost, as cost was a frequently cited barrier to the deployment of municipality specific software
- Provide mobile access
- If possible, the system should explore the use of a head-mounted display (i.e. Google Glass) as a hands-free communication tool

The system we built contained a wearable for the canine officer, a web portal, a mobile application, and a Google Glass interface [3].

5.1.4 System Description

We created a system that would address the key requirements. In this section, we describe each component of our system, beginning with the wearable for the dog.

5.1.4.1 Dog Wearable

We opted to instrument a Ray Allen K9 harness [98] (Figure 21) for the dog to notify officers using the system about the following events:

- When they have found the explosive
- Whether the explosive was stable or unstable
- To send the signal of where this scent was located

The wearable activation interfaces were modeled on the principles of Georgia Tech's FIDO project [59]. Our contribution is not in the design of the harness, but in its integration into our system. Because the most pressing tasks require binary discrimination between two alternatives, we relied on two interfaces (bite and tug) to each generate one alert. Each interface relied on a specific sensor. The bite interface relied on a capacitive sensor composed of four metal plates. The tug interface relied on a stretch resistor (10 cm) attached to a brightly colored ball placed on the side of the dog harness. Finally, we used an infrared proximity sensor (VCNL4000) to detect when dogs were in a 'down' position. This sensor was instrumented due to the 'down' position being the most frequently used for the dog to alert their handler that they found something of interest. Each one of these sensors was connected to an on-board micro-controller (ATMEGA 328) that polled their values every loop-cycle as described by Jackson et. al [59].

If a predetermined threshold value for any of these interfaces was exceeded an alert was generated. The Arduino-based hub sends a Bluetooth message to a ruggedized cellphone also contained in the waterproof box (OtterBox 1000 Series case) within the hub. This phone uses an internal GPS module to determine where the harness is and sends a message to the API with the current location tagged.

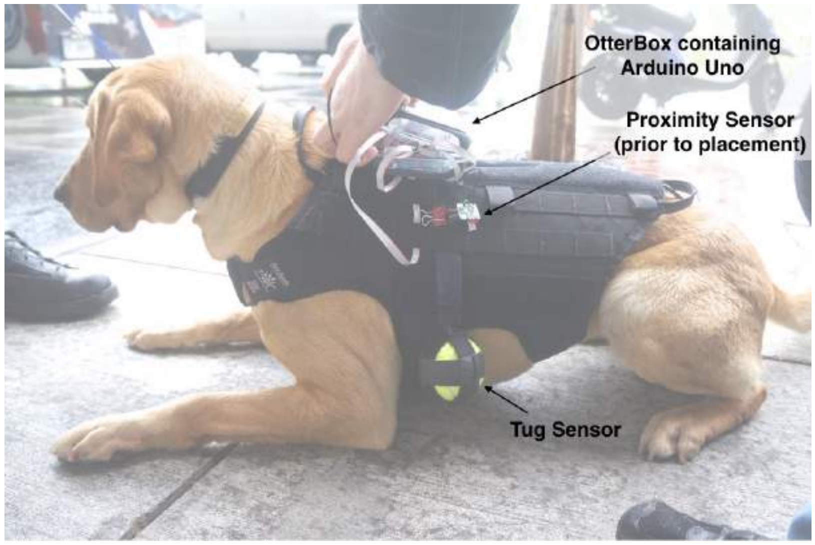

Figure 21: K9 officer modelling the vest with tug sensor to indicate "Unstable Item Found"

5.1.4.2 API Overview

Once a dog triggers an interface, the Arduino serializes the resulting signal and sends it to a smart-phone attached to the harness. An application running on the smart-phone then takes that signal and translates it to a RESTful JSON request [66]. The API controllers listen for these requests and take corresponding action to create, update, or destroy models in the Postgresql database hosted on Heroku [77]. Once the models have been touched, the web service utilizes Pusher to update all clients (web or mobile) with the new data. Utilizing this technique, events can be triggered on the harness and all clients will be notified in real-time. A diagram of the architecture is found in Appendix B.

5.1.4.3 Web Portal

The web portal is built using Ruby on Rails and hosted on Heroku. We have developed a fully functional web portal (Figure 22) for analyzing and managing events [31]. It is primarily used in an after-the-fact manner for documenting events and analysis of dog activation data. With these goals in mind, the web portal has been designed to deliver its data in a straightforward manner that facilitates searching through the documentation. It has been designed and built to feel like an application. To achieve this interaction, we have utilized Web 2.0 techniques such as AJAX and JavaScript to allow real-time modifications and live updates to the website.

The *recent events* page contains a list of all search events organized based on how recent they occurred. A search box on that page allows users to search through all events, and provides auto-complete functionality for quick and accurate searching. The events are indexed through a NoSQL-based system powered by ElasticSearch [42]. This system indexes all fields of the event model so users can search by alert, description, and location. The *current K9* page allows users to manage the current status and training certifications of the dogs in a K9 unit, which is made up of at least two K9 teams. Additionally, users can click the *recent events* button to browse events involving particular dogs. This *Maps page* provides a geospatial overlay of all events within 30 miles (48.2 km) of the user's location. Events are clustered by location to allow for quick navigation and identification, and once an event has been found, users can click on the event name to navigate to the recent event page of that event.

5.1.4.4 Mobile phone application

The application ('app') is divided into three sections (Figure 23). The first two sections are applicable to all officers that are working alongside K9 teams, while the last section contains an item that is (*training session details*) specific to canine handlers:

1. View all the department's K9 teams in a list and display a map of the position of each team member

2. Review current and past events dealing with scent detection events

3. Record details from training sessions with the K9 teams

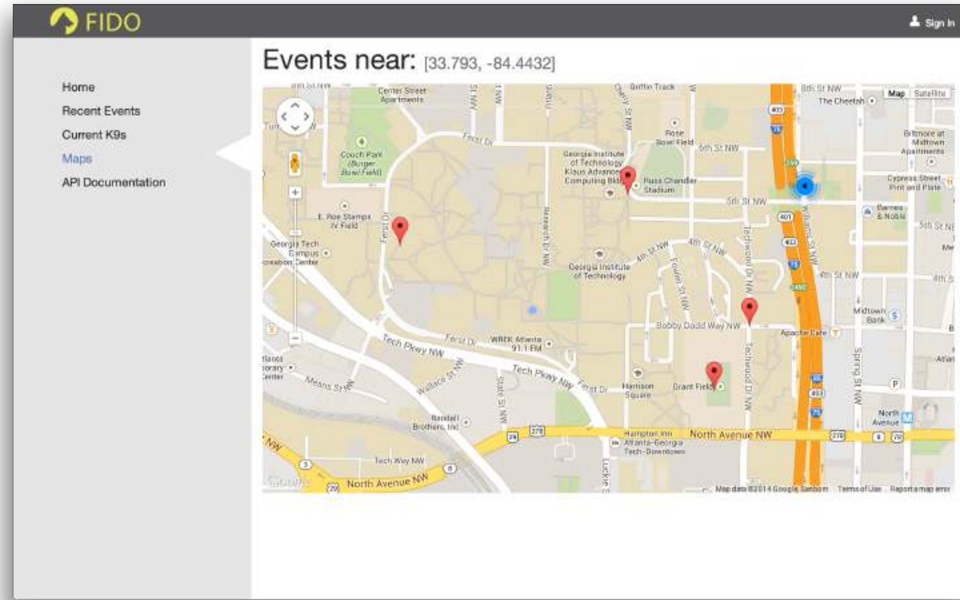

Figure 22: Maps page showing geospatial overlay of all events within 30 miles of the user.

The most prominent feature of the map is a map view of all the canines and officers actively participating in a search (Figure 23). We found that a map view of every canine allowed the user to perform actions like quickly find the nearest canine to some target location. In addition to the map view, there is also a list view which displays a list of all the canines in a given department with a name and picture. In the app, both views are presented and can be switched by a toggle button. The app remembers the user's preference and persists that view across launches.

After selecting a dog from either view, the user gets a few more details about them: current status, current location, and the ability to get directions to that location. However, more details are hidden in an information panel that is revealed by hitting the *Info* button in the top right corner. This button shows the K9 handler's name, dog age, team certifications or training, harness interfaces, and recent events for that K9 team. It also gives the user a chance to subscribe to a specific K9 team on various devices. Subscribing to a K9 team allows the activity and training details for that

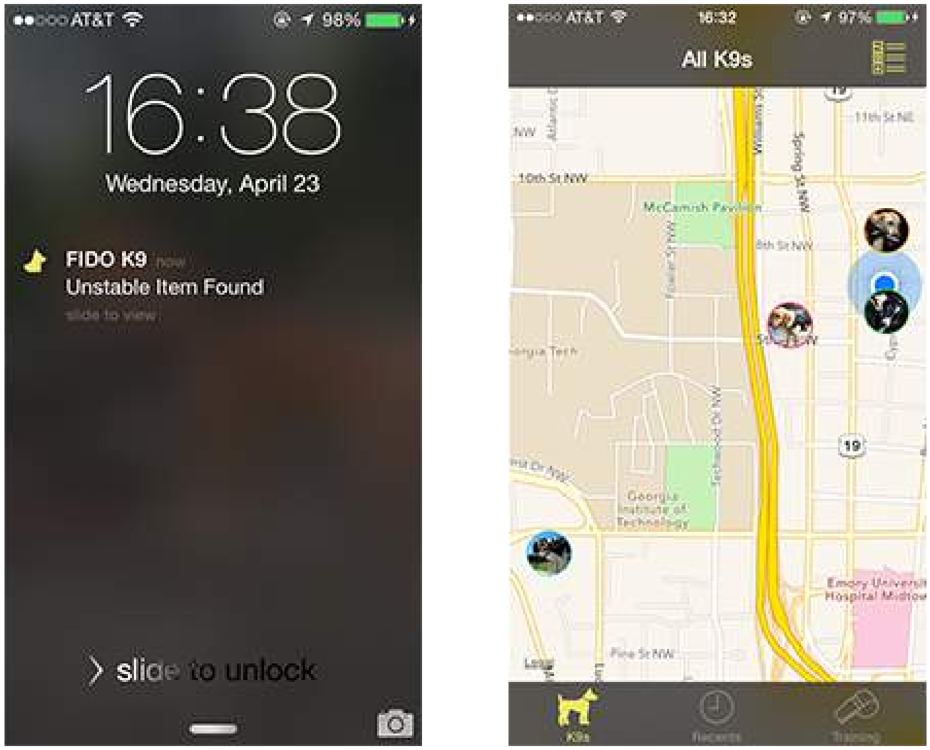

Figure 23: Event alert screenshot [left], and canine location overlay [right].

team to be followed. While the Info view gives an overview of the canine's details, certain cells can expand on their short summary. For instance, all of the harness interfaces (as well as other possible attachments) can be shown with details. The officer could also browse a complete list of their certificates and completed training.

Events contains information on the search tasks. When canines are in the field, officers need to be notified whenever important events, like detection of a scent, occur. Activating the notification (or navigating within the app) takes the user to the event view. This view displays important information about the search: the canines assigned, the trails of their past locations, locations of harness interface activations, and resources associated with the event (Figure 24). From here, an officer can quickly get directions to the location, as well as augment the event with additional resources such as images captured at the scene.

The map in the event view is dynamic, allowing officers to zoom in to see more

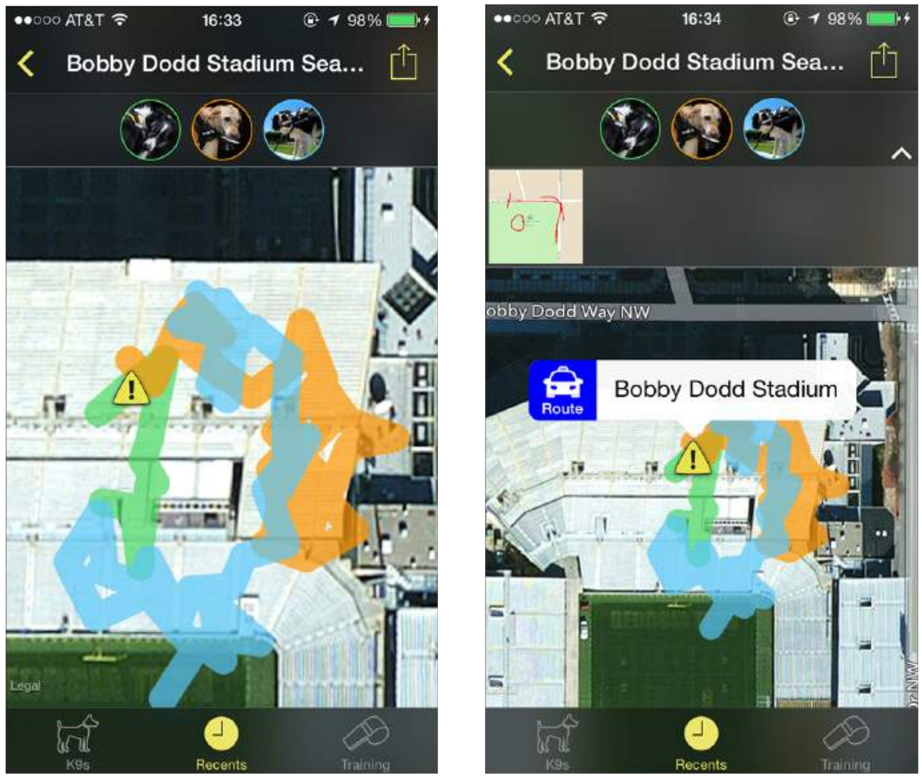

Figure 24: Example of K9 search activity [left], and officer annotations [right]. Each color represents a K9 team.

detail or focus on specific dog trails. This behavior is also important when officers add their own annotations to a map, as officers can continue to pan and zoom in the map, while their annotations stay associated with specific latitude/longitude points.

These map annotations, as well as any user photos, are uploaded to the FIDO K9 server for later viewing and analysis. These resources, as well as pictures taken by officers at the scene, are also available within the app.

When the CPD (like most K9 teams) perform training exercises with their K9 dogs, there is a large document, the training log, that must be completed with details about the training. The officers fill this paper document with the information, and then transcribe that into a spreadsheet when they return to the office. This transcription takes additional time and requires the officers to look up information that is needed for the spreadsheet like weather details.

Instead of creating a one–to–one mapping from the paper form to the app, we sought to automate the form as much as possible. With the information the app already has on the K9 teams, several fields were made easier: dog names could be selected from an auto-populated list, and the handler would not need to be specified by the user, because it is already known by selecting the canine. The training location can be set using the phone's location (given the user's permission). Similarly, we are using an API provided by Forecast.io [35] to get hyper-localized and detailed weather information at the user's location. This API allows us to automatically fill out tedious details such as the humidity, overcast, and wind speed. When creating new training aids, we are able to use similar techniques to reduce the number of required actions by the CPD. By integrating this training information into the smart-phone app, the time to complete the training log is significantly decreased.

5.1.4.5 Google Glass

The promising results of Johnson, Gibson, and Mutlu coupled with the officers interested in utilizing department purchased Google Glass motivated us to integrate this device into our system [62]. In our system, Google Glass [71], the head-mounted interface, supports real-time communication and collaboration between the dog, the handler and accompanying officers. It can display and transmit much more information with minimal diversion of the officer's gaze. Glass allows officers working with a dog to get real-time updates on what the dog is alerting to, as well as augment the canine's feedback with their own input.

Live cards (from the Google Glass UX design kit) support ongoing tasks, such as emergency incidents, and allow the officer to request additional backup. During a search, the handler wearing Google Glass will be able to see the current location of the K9 team, as well as the path already searched. When the dog scents a suspicious object, a signal would be sent to the handler's Google Glass to trigger it with a sound to notify the officer of the emergency. If the handler needs additional backup or support, he could send the request along with information from the dog whether the explosive device is stable or unstable to Dispatch. Officers wearing Google Glass would receive the notification and view the event, and get directions (Figure 25).

Figure 25: Google Glass providing directions to officer.

In this scenario, we predict the time that it currently takes to route an alert to the appropriate department would be minimized. While awaiting the arrival of backup officers or the EOD unit, the K9 team will be able to see the current location of backup. They would also be able increase documentation by taking photos or videos of the package and its surrounding area. When backup arrives on the scene, they would be able to see the location of both the handler and the item. Once the K9 alert is resolved, the handler can dismiss the task and all accompanying officers will be notified that the situation has been resolved.

In addition, officers wearing Google Glass can access the static cards for more information. The static cards display text, images and video content. The content could contain text information about an incident, images or video of suspicious objects. Static cards are documentation of past events.

5.1.5 System Demonstration

We demonstrated a functional prototype of our system during an explosive detection training session with one K9 explosive detection team. For safety reasons, we were not able to participate in live searches because our participation might compromise the integrity of the process. We saw this training session as the closest environment we would be able to participate in to simulate our system without compromising safety. This training session involved locating a specific scent inside of a building on campus. A second team observed and commented on the training session. These officers were part of the original group that was observed during the requirements gathering process. They also provided feedback on the mobile phone app prototypes on two occasions prior to the functional prototype explosive detection trial. The latter feedback session included a walk-through of the high fidelity mobile phone app prototype and was invaluable in shaping the design of the application [101]. Due to security concerns we were unable to deploy the app in-the-wild. Concerns around the impact on the current training practices of the officers also prohibited us from conducting a field evaluation outside of the demonstration of the functional prototype.

5.1.6 Findings & Contributions

The mapping interface with collaborative annotation and scent alerts was universally valued by the officers. They expressed that this technology allowed them to coordinate searches better than using radio transceivers which were often not universally accessible. Being able to download an app and quickly communicate with other officers as well as see the updated map would remove many of the barriers to communication as it was not restricted to a specific municipality. One officer (P2) said, "I like the fact that we could live track our active K9 teams during a sweep to find out the areas that had been searched already. This feature allowed us to search more efficiently because we could simply look at the application to determine what areas still needed to be searched. This could be done much more quickly than having to call each handler for an update." [58]. The officer (P3) who routinely provides backup for K9 teams, saw value in the app beyond working alongside K9 teams:

> "This program enables law enforcement personnel to input vital information in real-time and keeps all personnel on the same page. Managing personnel in a crisis situation is a daunting task, especially when hundreds of lives could be at stake. This tool would greatly ease the logistical nightmare of keeping track of our personnel and assigning/ reassigning posts as critical information evolves."

5.1.7 Discussion

The simulated alerts generated through the instrumented dog harness were well received by officers. Nonetheless, the officers were concerned about the practical difficulties the harness could encounter during searches. For example, the freely moving (hanging), wearable interfaces (tug and bite) could catch on nearby objects. Because search environments are often hard-to-reach and compact, this limitation posed a non-trivial problem. Nonetheless, the ability to signal to handlers provides a way to decrease search time and minimize fatigue.

After our prototype simulation during the training session, we decided to focus on the mobile phone application. Instead of making the dog harness smaller, we wanted to explore a different method for the dog to communicate with the handler that would not involve freely-moving (hanging) interfaces on their body. This in turn led to our exploration of intentional gestures (described in Chapter 3) that could be classified by an inertial sensor and communicated wirelessly to the handler's mobile phone [122]. We believe that this direction can better address the needs of our users, both human and canine, and will unite what is most promising in our system.

One thing we did not adequately consider were the changing regulations for law enforcement concerning the security of and availability of their search data. With the testimony of K9 teams being a valuable part of legal proceedings, it is important to be transparent, yet also secure, in how we handle these data [85]. As with concerns around handlers inadvertently cueing their canines to alert [69], so could concerns arise around the documentation of the canine alerts in our system.

5.1.8 Limitations

One of the technical challenges we encountered was indoor location sensing. For example in multi-level environments (e.g., sport stadiums), GPS alone is insufficient to indicate the floor of the alert. Due to this limitation, the environment where our current prototype system can be successful is restricted and does not cover all of the environments in which these teams work.

The officers agreed that the head-mounted interface was not as useful as the mobile phone app because there was no way to securely attach it during the vigorous movements of a search. Similarly, the mobile phone app did not affect visibility and had longer battery life than the head-mounted display. There was interest however in utilizing some of the aspects they appreciated such as gesture control (similar to those built into Google Glass) and hands-free glance-able notifications but in a different form factor like that of a watch.

Similarly, due to the mobile nature of police work, officers predicted they would rarely use the desktop web interface, even at the police station or inside their cars. Instead, we found the web portal is better-suited for a different audience, namely dispatchers.

5.1.9 Conclusions

Further development is needed on the mobile phone application to integrate voice communication and better track indoor location. We believe that the Apple iBeacon [76] might be a promising, low-cost option for indoor location in frequently searched sites like sport venues. Use of this technology, which is currently being deployed at multiple stadiums in the United States, is planned to be tested on our campus this year [125]. In addition, we also need to alter how we handle K9 team search data to meet regulations established within this past year.

By making the app freely available, barriers to implementation around cost would be removed. While not all officers had access to head-mounted interfaces such as Google Glass, they all had a department-issued smart-phone. To prevent the same issues that the current systems have from being repeated, future work should also add a voice channel, thereby covering each of the communication channels the officers need in a universally accessible application.

We hope that by sharing our diagram, information on the current process, and system prototype details with our community more research will be done in this under-explored space. Initial response to our work has been positive and law enforcement officers have provided actionable feedback. We are encouraged by the response and believe that this system has the potential to improve the lives of K9 teams, law enforcement officers, and the communities they serve.

5.2 Puppy Accelerometer Data for Working Dog Suitability

5.2.1 Summary

The Puppy Accelerometer data for Working dog Suitability (PAWS) project is framed within Action Research with a goal of generating transferable knowledge. This work began when my collaborator, Canine Companions for Independence and I began discussing the potential of the use of accelerometers for gathering longitudinal movement data on puppies in the Spring of 2014. Canine Companions for Independence (CCI), a service dog training organization, had a hypothesis that overall activity level could correspond to the suitability of a dog for a specific job. The subsequent study design, placement of devices, and data collection have all been conducted alongside researchers at Canine Companions for Independence. Wearable devices for the dogs, supplied by Whistle Labs, were placed on 133 dogs beginning at 8 weeks of age. Placement began in June of 2014 and ended in January of 2015. To my knowledge, this is the largest data-set of its kind. The processed data, with IMU values converted into activity levels and categories of activities was available within one hour of the activity throughout the study. At the conclusion of active wearable data collection period, which lasted until the dogs were 22 months old, a website hosting this data with visualizations was created for Canine Companions for Independence. Does the increase in the quantity and accessibility of information as provided by the PAWS system improve the dog–occupation matching process as evaluated by Canine Companions? In this chapter I will share the story of this project, as well as reflections on being a part of Canine Companions as a volunteer, raising and training one CCI dog (Figure 27). A broader reflection on the dissertation as a whole can be found in the following chapter.

5.2.2 Motivation

The set of skills required for working dog success vary across occupations. These skills include perceptual, cognitive, and physical abilities, in addition to specific ways of working with humans, dictated by each occupation. Canine Companions dogs are bred and sent to volunteer homes to be cared for from the age of 8 weeks to 18 months. These volunteers, commonly called "puppy raisers," foster the dogs in their homes and provide basic training such as housebreaking, leash walking, and simple commands. When the puppies reach approximately 18 months of age, they progress to advanced training. During advanced training the dogs live in a kenneled environment and learn specialized skills that are needed for service dog roles. At that time, professional trainers evaluate the young dogs to determine their suitability for a particular occupation. Dogs that are removed from consideration from CCI occupations are considered “released.”

Canine Companions provide dogs in assistance dogs that work with people with disabilities. They train dogs to assist people with physical disabilities and hearing impairments. Companion dogs for children (or adults) who may not be able to live independently and facility dogs who work with a therapist or teacher are also trained by CCI.

Increasing the success rate of training outcomes is a frequent topic of research interest in the working dog community and in particular at Canine Companions for Independence which currently has a success rate of 40 % . Many attempts to improve these outcomes aim to predict a dog’s suitability for an occupation before the costly training regimen is started. As described in Chapter 2, these assessments are currently based on behavior tests, lateralization tests (‘handedness’), and surveys filled out by human caretakers [118, 108].The most accurate method to date required a great deal of expert monitoring and assessments that are not scalable for a large dog population [111]. Canine Companions currently tracks the performance of each of their dogs alongside the genetic data they collect, looking at outcomes often by litter, sire, and dam. Surveys on the dog’s behavior while in the home are completed by the puppy raisers each month. Although these surveys have not been studied by Canine Companions for value in predicting outcomes, they do refer to these reports particularly when a behavioral issue is identified in advanced training. The search for precedence of the issue in reports is used not to create a reprimand for the volunteer, but is instead used to potentially form the basis of releasing the dog from Canine Companions for Independence service.

While there are multiple factors that contribute to the high costs of training a working dog, one of the largest is the inability to determine which occupation each dog is best suited for prior to advanced training. During advanced training, the dogs are kept in a kenneled environment unlike the home environment where they have spent most of their lives. This transition is stressful for many of the dogs and it requires a different method of care than in the home. In particular, the level of interaction with their primary caretaker is different. When in the homes, the volunteers feed and care for the dogs, while in the kennel during advanced training, Canine Companions for Independence covers all care costs. In addition to the financial cost, being trained for an occupation that does not match a dog's temperament can result in a great deal of stress for both dogs and trainers.

5.2.3 Research Questions

The following research questions are of interest to Canine Companions for Independence:

1. Is it possible to determine a high probability of failure at 6 months?

2. Is overall activity level a better predictor than overall rest?

3. What are the implications on current practice with such devices?

By working alongside Canine Companions for Independence to answer their research questions, I am also addressing two of my research goals:

1. Design systems and actions that support these interactions.
2. Improve the information flow in doghuman interactions through wearable systems.

In addition, I am interested in exploring whether CCI can generate their own hypotheses for suitability if we provide visualizations for the accelerometer data.

Better predictions of working dog success and understanding which job would be the best fit would be a significant contribution to veterinarians, animal behaviorists, and handlers of both working dogs, in particular Canine Companions for Independence , and pet dogs.

5.2.4 PAWS System

In order to explore the research questions, we created PAWS. The PAWS system includes a commodity wearable device, the Whistle Activity Monitor (Figure 26), its companion Whistle smartphone application, and a custom-built desktop web dashboard accessible only to the research team.

The workability of this system has been evaluated by my CCI collaborators. They focused particularly at looking at the role this system plays in supporting and providing insight to both the caretaker for the dog in the home environment (prior to admission into working dog training) as well as the working dog practitioners who monitor the dogs remotely and while they are in their care during advanced training.

5.2.4.1 Puppy Wearable Device

For this study, a large group of puppies (133), from multiple litters has been equipped with a Whistle Activity Monitor (Figure 27).

Figure 26: Whistle Activity Monitor.

The Whistle Activity Monitor contains a tri-axial accelerometer, sampling at 50 Hz, coupled with Bluetooth and Wi-Fi functionality. Bluetooth allows the device to detect the presence of a smartphone belonging to the dog's caretakers. When connected through Wi-Fi or Bluetooth this device updates hourly and provides activity reports in the smartphone application. The device weighs 16 grams, has a battery life of 7-10 days and has been validated for research purposes in a kennel and home environment with dogs over 9 lbs (4.08 kg) during its usage in other studies [6]. The 16 gram weight of the Whistle on a dog that is at least 9 lbs (4.08 kg) is significantly below the maximum weight guideline of 4-5 % by Yonezawa et al. [130].

Figure 27: Canine Companions puppy in training wearing the Whistle Activity Monitor

5.2.4.2 Smartphone Application

The Whistle Activity Monitor syncs with the companion Whistle smartphone application (Figure 28). This commercially available smartphone application runs on both iOS and Android operating systems. The activity information in the application updates hourly when the smartphone and activity monitor have Internet connectivity. Activity information is not dependent on physical proximity to the dog, which allows puppy raisers and CCI staff to remotely "check-in" on their dogs even when they were away from the dogs. Activity and rest events, called Insights, are displayed automatically for each day. Puppy raisers and research staff are able to comment upon each of these entries. These Insights are shown below the daily activity intensity graph. This application was designed for a single or small number of dogs residing in the home and was not custom designed for Canine Companions or any kennel environment. This means that there is no option to view more than one dog's activity or day at a time. To view this information, the application user would need to toggle between the list of dog names accessible from the menu on the top left and view each dog's data individually. While this individual viewing has not been an issue for the puppy raisers who typically only raise one dog at a time, it has been onerous for the Canine Companions staff.

The application supported the addition of photos that were kept private by default and only shared amongst owners of the dog registered in the application, in our study these included the puppy raiser, their family, and our primary collaborator in CCI research. Highlights from the dog's day, whether in the form of activity milestones or photos, could be pushed to social networks. Whistle app users were also able to create notes that corresponded to the dog's day, comment on specific Insights, and create notations for meal-times. Owners could also note the date and times medications were given. In addition to the information available in the application, Whistle Labs sent weekly emails on the activity and rest trends of the dog.

Our research team sent emails on the battery and syncing status, as well as overall activity levels generated via a custom Python script to our CCI research collaborator at pre-specified intervals. These emails were an attempt to address the gaps in monitoring the usage of the device that were not addressed in the companion application and its single dog view.

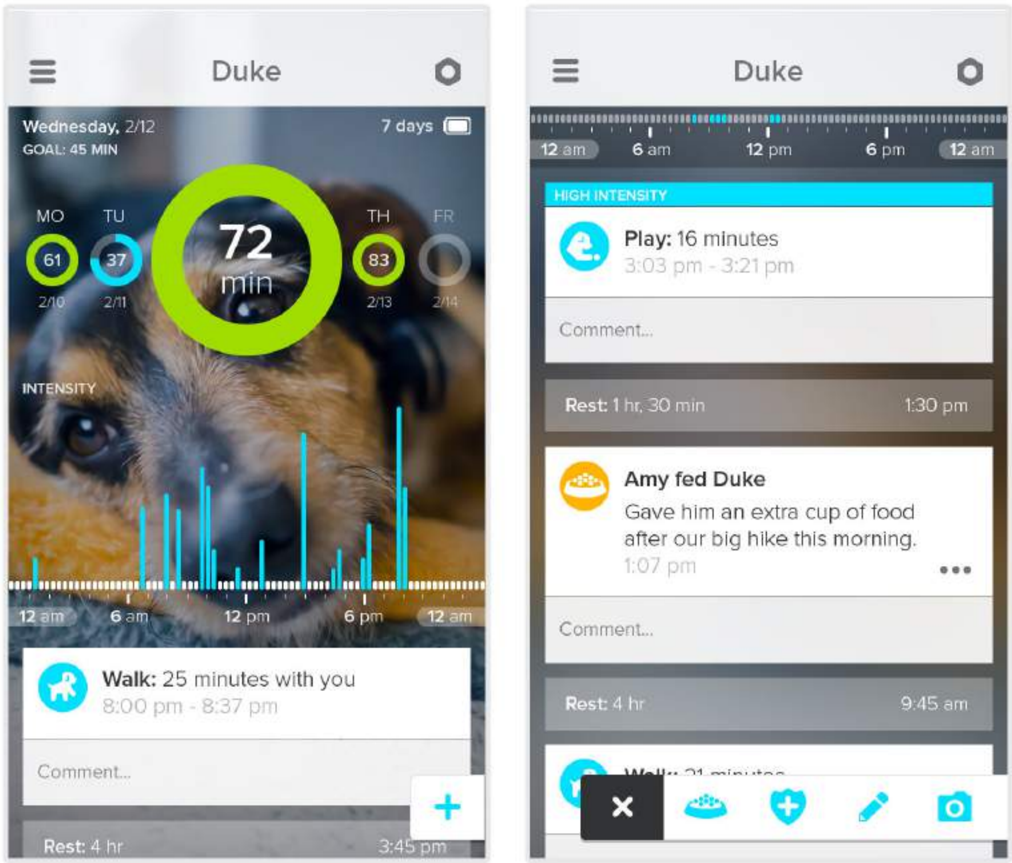

Figure 28: Whistle Mobile App.

5.2.4.3 Desktop Web Application

A desktop web application that allows Canine Companions staff to ask questions of the accelerometer data set and generate visualizations was released in February of 2017. The goal of this application is to allow for exploration of the data in a way that is accessible to the CCI staff that do not have a background in machine learning or experience with IMU data. Few of the staff have experience with statistics and so our goal with this dashboard was to be flexible enough to allow those with a statistical background to generate and evaluate their hypotheses while also allowing the user interface to provide meaningful information to those without this background. The dashboard is shared amongst all of the individual users, however the user-generated graphs are specific to each user.

The graphs we have chosen to use range from standard distribution graphs to box and whisker graphs which help show important outliers. Although Canine Companions has had access to the activity data in a shared online storage account, there are several challenges with the format of this data that it has been prohibitive to exploration by CCI research staff. A main reason why the data itself is hard to read, understand, or interpolate is because it is rare that a dog has the same wearable device throughout the study. A separate shared file was kept that would log which dog was wearing which device serial number and the dates in which it was switched. All dogs in the study were "tagged" on the Whistle server while I was a Research Scientist intern at Whistle labs in the Summer of 2014. These tags allowed me to identify and track which dogs were part of my study and to generate daily and hourly activity reports. The frequent switching of devices as well as gaps in the data from the dog either not wearing the device or it not having access to the internet for an extended time period, made data formatting a non-trivial task. In order to allow CCI researchers to be able to track their dogs data through these numerous devices, we re-organized the csv activity files and identified any gaps in order to map dogs by name to their their corresponding data points. Our application is designed to show information about activity and rest attributes as well as graduate dog outcomes through human readable, presentable graphs Figure 29).

Since CCI staff use a variety of devices and platforms, although primarily while at their desk, we built this tool as a web application. We began development on the web application began in September 2016 and currently, as of the writing of this dissertation, development is ongoing. The application uses HTML and CSS as the pillars for structuring the design of the web based application. This allows the application to be viewed on any platform that has access to the internet. Javascript is used for obtain the data about the dogs and allow for the data to be parsed. Javascript allows for the application to generate graphs and charts, as well as run

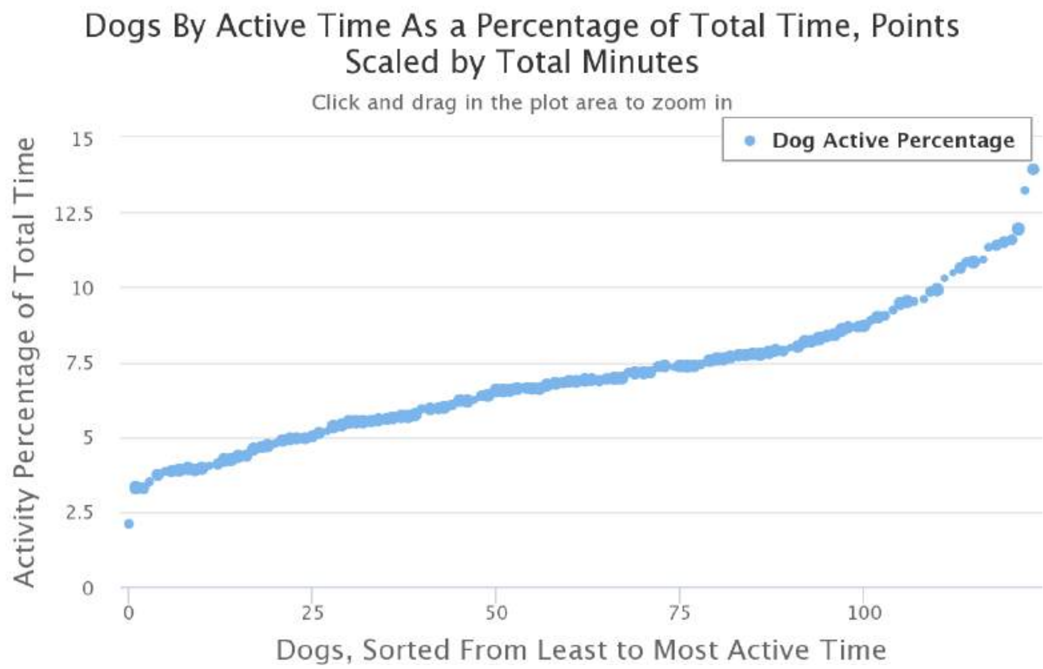

Figure 29: Graph generated by PAWS web dashboard.

statistical tests, based off of the input of the user.

For the hosting service we chose to use Google App Engine as it will require minimal administration by CCI in the future and because the services pricing is usage based per day and has a perpetual free limit of resources that can be used on a given day at no-cost. App Engine allows the application to be always available on short notice upon opening the website, while minimizing costs for unused resources over time. This allows us to greatly limit costs, which is important for continued maintenance by CCI, a non-profit. We expect to maintain a relatively low load on the server and database through caching data and performing rendering and other application-level tasks on the client where reasonable.

Based on the needs of Canine Companions staff, we implemented the following features:

Custom Creation of Graphs by User: the need to create graphs within the application by selecting the data sets and graph types they wish to use. The user can pick from a variety of subsets of dogs and generate relevant graphs to compare the data.

Series Grouping Capabilities: ability to group data sets and dog data into groups to be displayed on their graphs. Interactivity: Interactive functions include, zooming, dragging, scaling, etc. Therefore when selecting a library we also favored those which included implementation of these functionalities within their graphing libraries or allowed for the capability to add these functionalities onto the library ourselves within our application. Complex Graphing Capabilities: when selecting a library we preferred those that already had the functionality set out to implement complex charting systems like box plots, scatter and bubble plots, 3D axes plots, regression lines, and so forth.

Highcharts is the main visualization tool of the application [64]. HighCharts provides fully customizable, built in charts that allow for the creation of both simple charts like line charts up to complex charts like box and whisker and combination axes charts. HighCharts is also is natively designed to be created with javascript and rendered in HTML without any additional setup. This should make maintenance and alteration by Canine Companions much simpler while also achieving the complexity level they require in need in terms of the analytical visualization of the data. Highcharts also allows for functionality like zoomable graphs, downloadable graphs, combinations, scatter and bubble plots, 3D plots, dynamic charts, heat and tree maps, polar charts, etc. jStat, a Javascript statistical library, is being used to generate statistics and run tests on the data being graphed. It provides both basic functionality such as the mean and quartiles, as well as advanced functionality in the ability to run t- and z-tests to find p-values.

The two years of dog data collected were originally stored in .csv files. These have been transformed into organized json format files which we fetch from our AppEngine database using JQuerys ajax request feature. Bootstrap.js is also used in order to keep our web application responsive to any screen size. Researchers and staff at CCI do not only use desktop computers but also utilize iPads and mobile phones throughout their work day, therefore we wanted our interface to accommodate those needs by being responsive.

In addition to the features listed above, the application features a help menu and a secure login that enables email and password verification. Support for the creation of this application was provided by a team of Georgia Tech undergraduate Computer Science students.

Work on this application will continue after my dissertation in order to ensure that Canine Companions for Independence has the necessary support. One of the features currently in development is the ability for additional Whistle Activity Monitor devices to be tracked and added to the data set from the original group of 133 puppies. This will allow the application to remain useful to Canine Companions after the original group of puppies are no longer wearing the activity monitors.

I delivered a walk-through training session on this web application with members of the Canine Companions research team following their interviews during my on-site visit in February.

5.2.4.4 Anticipated Activity Data Collection Challenges & Opportunities

When this study started, I imagined that the most notable challenge would be the effect that the sensing technology could have on the behavior of the dog and the dog's caretaker. For example, the smartphone application displays the minutes of activity which could influence the dog-walking habits of the puppy raiser. In addition, I anticipated that some dogs would attempt to remove the activity monitor from themselves, despite its size being comparable to that of dog tags. Dogs who exhibited this behavior and removed the monitor would be disqualified from the study for safety reasons. Challenges of this nature have been described by Westerlaken et al. [127]. Canine Companions did not report any dogs having their activity monitor removed for this reason while in the puppy raiser homes, but did remove the activity monitor from less than 10 dogs for safety concerns while they were in advanced training.

I did not anticipate was the extent of the technical challenges. The need to pair the activity monitor with a smartphone, and connect the activity monitor to a wi-fi network was a significant technical hurdle for many of Canine Companions volunteers and required multiple troubleshooting sessions. When interviewed, P2, who was the primary contact for the puppy raisers said: "I mean a lot of our volunteers were not really part of the target market for this product so it took a lot of upfront explaining of technology in general to get them to the point where they were able to use it and understand it. Once they did, many of them liked it and enjoyed seeing it."

The goal of this research is to generate knowledge that is helpful in building a better solution for Canine Companions and to that end, human behavior change is not seen as a negative or a confounding issue but instead is a learning opportunity. There is also an opportunity in looking at non-users, as well as the instances where there are no technical hurdles for participants [119]. While the dog's safety is of primary importance we did not take situations of the dog removing the device or damaging it to mean that this research is invalid, but used it as an means to learn how to build a device that will better meet their needs after completion of this dissertation.

5.2.5 Methods

5.2.5.1 Data Collection

We placed the wearable devices on dog collars as they enter puppy raiser homes at an average of 8 weeks of age. Placement began in June of 2014 and ended in January of 2015. The puppies wore the devices continuously (when not charging for an hour per week) and the devices remained with them as they entered advanced training. The puppies wore them for at least the first two months of advanced training. Advanced training takes place in all six of Canine Companions regional training centers. However, hearing dog training only takes place at the Northwest region which is also where the headquarters of Canine Companions is located. Each regional training center, was allowed to remove the devices after two months (or earlier due to safety concerns) or could leave them on the dogs longer. The duration of how long each dog wore the device in advanced training after the initial two months was at the discretion of the regional training center. Placement decisions will not be made based on this set of data.

The sample population, consists of 133 CCI dogs, ranges in age from 8 weeks to 2.5 years old. Their breeds include Golden Retrievers, Labrador Retrievers, and crosses of these two breeds.

5.2.5.2 Puppy Raiser Involvement

Due to the volunteers raising the potential working dog puppies in their homes, their consent and continued participation was needed during the duration of the study while the dogs were in their care. While the dog is in their home, the puppy raisers will be responsible for keeping the devices charged and syncing them with the companion application.

Although the requirements for continuous data collection are few, due to hourly over-the-air synchronization, the need to maintain a battery charge on the activity monitor and ensure Wi-Fi or Bluetooth access is ongoing. Maintaining these requirements for extended periods of time was challenging for many volunteers. Reports of what this experience has been like have been shared with the Canine Companions staff that I interviewed, including the national manager of the puppy raiser program.

During the study, while in puppy raiser homes, 13 dogs had the data collection end prematurely. One of these dogs had the activity monitor removed due to being released from Canine Companions for a medical reason. The 12 other dogs had their data collection end prematurely due to the withdrawal of the puppy raiser from the study. Of the 12 puppy raisers who withdrew from the study, one did so within 2 months of data collection, three at 5 months, four at 6 months, one at 7 and 9 months, and two at 11 months. The primary reasons the puppy raisers provided to the puppy program manager and research coordinator, for withdrawing from the study were related to technical challenges and the time required to maintain the technology.

5.2.5.3 Canine Companions Staff Interviews

A series of interviews with Canine Companions staff members was conducted in February of 2017 (Appendix: Figure 32). These staff members have all been involved with the research, one in particular has served as the primary collaborator. A total of five interviews were conducted. The interviews were semi-structured and were conducted with a goal of assessing the workability of the PAWS system.

5.2.5.4 Interview Protocol

Canine Companions for Independence staff were asked to participate in one interview (Appendix: Figure 32). The shortest interview was nine minutes forty-three seconds, and the longest was one hour and four minutes. The average interview time was 35 minutes. All of the interviews were conducted at the participant's workplace, which is the headquarters of Canine Companions in California. Their various roles included researcher, manager, and caretaker.

All interviews were audio recorded and then transcribed. A qualitative coding analysis was conducted to determine the themes that emerged.

5.2.5.5 Data Analysis

Based on prior animal behavior research, for the accelerometer data, there are a few key trends we planned to identify to examine correlations with training outcomes, these included:

- Activity changes upon entering Advanced Training.
- Rest habits.
- Overall activity levels.

On the interview data, we planned on looking for anticipated and emergent themes to qualitatively analyze the answers to the questions provided. Anticipated themes are around sense-making techniques, usability challenges, and usage trends (Appendix: Figure 33). The complete codebook that contains descriptions and examples of each code is located in the Appendix, with selections from it appearing in the Findings section.

The credibility and validity of the knowledge generated from the interviews and this research will be measured by the ability of PAWS to address real problems in the lives of the Canine Companions for Independence puppies and staff.

5.2.6 Findings & Contributions

While there was an increase in the amount of information that Canine Companions had about the dogs, and this information was more accessible, activity data alone, specifically overall levels of rest and physical activity was not predictive of training outcome. It is possible that the activity level could be an indicator of training outcome, but that it is such a weak indicator that we were not able to see it in our small sample of 133 dogs.

During the interviews I was able to explore the usage of the system as well as unexpected contributions.

One of the unexpected contributions was using the real-time data on a specific dog to alter the environment. Prior research had shown a connection between restlessness at night and training outcomes [5], and so Canine Companions staff were looking at evening activity closely during the study. Although the change in environment including housing and training practices did not alter these dog's outcomes, the information provided on their evening activity was considered a "red flag" or predictive of their eventual release.

The tables below are selections from the complete codebook which can be found

Table 10: Data Access - The dog wearable is collecting data on the dogs. This code concerns access discussions and decisions around the control of these data.

Code	Description	Prototypical Examples
Sharing	Sharing of the data	"I would like all of the regions to be able to see this."
Privacy	Privacy of the data	"Even though it might be good to see the data and check-in with the volunteers, I'm worried it might be seem like an invasion of privacy."
Control	Who owns the data and who sees this data	"But I'm just careful who has access to that data, because I don't want at this point any decisions made about a dog just based on what they see. You have to be careful who sees what."

in the Appendix.

5.2.6.1 Data Access

Three themes emerged around accessing the data from the PAWS prototype (Table 10). These themes, sharing, privacy, and control, considering the content of the data we were collecting, are not surprising. What was surprising, however, was what specifically the implications were of the concerns around privacy and control.

"You know, we want to see that all of our dogs are getting sort of this range of exercise, you know. And if we saw a dog that was really low on the scale, then we might contact the puppy raiser. I imagine that could feel pretty invasive to the puppy raiser. I dont know. I would feel like it be a little bit Big Brother-ish." (P4)

As seen in the quote above, this staff member was weighing the perceived invasion of privacy of the volunteers against the potential value of correcting their dog care-taking habits. This also speaks to the current gaps in the data that is currently collected by the organization. This data is primarily in the form of self-reported monthly surveys which P4 says only 40- 50% of all volunteers complete. There had not been, prior to PAWS, as much visibility into what the dog's life in the volunteer home really looked like. With this new visibility, new questions have been raised in regards to how best to use it and where the line should be on what is considered helpful as opposed to an invasion of privacy.

Since this is an organization dedicated to breeding and training future service dogs, Canine Companions is focused on finding ways to optimize this process. The decision of when a dog should be 'released,' removed from active training status, is not one that is taken lightly by any of the staff members that I interviewed. It was concern, around this decision, and what factors might play into it, that discussions around control of the data came into greater focus. Prior to the interviews, I anticipated that discussions around data control would focus around the difference in who has access to the data as it pertains to staff and volunteers. While, this was a topic brought up in the interviews, surprisingly the link between control of the data and decisions regarding the a dog's outcome was the larger concern. This concern around control of the data and outcome decisions is likely not exclusive to Canine Companions , and I anticipate a similar tension among other organizations that breed and train working dogs.

5.2.6.2 Dog Health

Considering the kind of data that PAWS collects, the focus on dog health was anticipated (Table 11). What I did not anticipate however was the importance of stress in these interviews. With a relatively small pool of staff members involved with this study, I cannot say that their concerns are generalizable to all working dog practitioners. However, I do believe that there are transferable insights that can be found, particularly when working with a similar population.

Inside of the wearable device is an accelerometer. The data that this device collects relates to movement. Specific activities like running, walking, resting, and playing, are identified for a single dog inside of the companion mobile application. Percentage of time spent awake, resting, and active is shown for a single dog as

Table 11: Dog Health - Physical and emotional health of the dog.

Code	Description	Prototypical Examples
Overall Activity	Viewing the activity levels of a given dog.	"Seeing these overall activity levels is like having an opportunity to kind of observe a dog over time and you're not limited to a snapshot. You really get a more complete picture of their health."
Exercise	Viewing and discussing the amount of exercise a dog receives.	"I think it is something we need to look into, the exercise levels of the dog and how this impacts their health and performance in the program."
Rest	Viewing the rest or sleep data on a given dog.	"Some of the most interesting things we saw was around sleep. Are they getting enough rest at night?"
Energy Level	Discussing the perceived energy level of a dog as compared to others.	"We tend to put dogs with higher energy levels into specific job categories. A higher energy dog might not be right for any of our jobs."
Stress	Discussing the perceived level of stress a dog is experiencing and ways to intervene.	"Although we aren't getting a measure of stress directly from the PAWS tools, I like to look at what the dogs do in the evening to see if they are able to rest, instead of pacing, having high activity at night, which is a sign of stress."

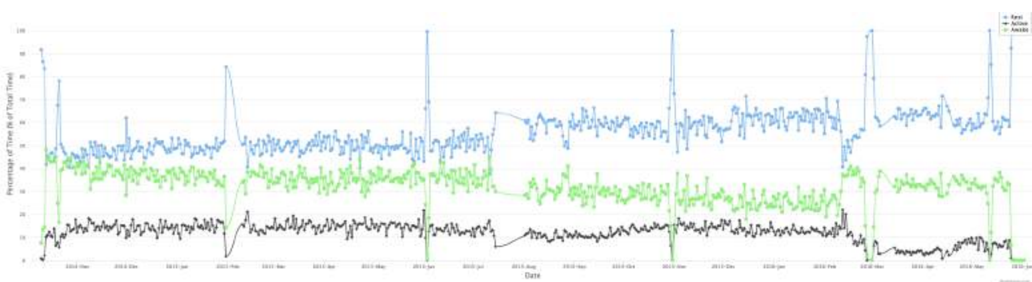

Figure 30: Graph generated by PAWS web dashboard of a single dog.

well as multiple dogs in the web dashboard Figure 30).In the weekly reports, and in the PAWS dashboard, overall activity, activity intensity, and rest are displayed for groups of dogs. Within the limitations of what kind of data the device can collect and classify, Canine Companions staff were able to make use of this information in order to infer a more complete picture of a dog's health. Since the device did not make a determination on a dog's stress level, I was surprised by the prevalence of discussions around stress when we spoke about the study. Using the data they had from PAWS,

Table 12: Prediction & Prevention - Data from the system being used to prevent harm and improve outcomes as well as predict success.

Code	Description	Prototypical Examples
Dog Suitability	Ad hoc discussions or decisions made about the suitability of a dog for a given job.	"One of the things we are interested in trying to predict is if we look at the dog's activity and we know their outcomes, could we have matched them just using the activity to determine dog suitability?"
Dog Expectations	Predictions made a priori on what to expect from a specific dog.	"We knew to expect a lot of energy from this dog based on what the volunteers said in their monthly reports. I personally did not really expect the dog to make it successfully through training."
Hypotheses	Hypotheses on the predictive properties of the data	"I have a few ideas about what is going to be important in this set of data, I think rest and activity are likely to be the most predictive."
Prevent Harm	Data used to prevent harm	"If I could know when the dog is flank sucking before I see the signs on their coat, I could treat it and deploy an intervention."
Prevent Training Failure	Data used to stage an intervention that attempts to improve the dog's training outcome	"Well, I have always thought that dogs who dont get enough sleep at night perform worse in training...so when I saw this dog wasn't sleeping, I tried changing his kennel in order to give him a better chance of training success."

staff members remarked on using the level of activity at night as a proxy for a stress indicator. This new data alone was often not enough to make a determination on the level of stress a dog was experiencing, but combined with other information it gave the caretakers enough evidence to make a case for an intervention. As P2 remarked, "The dog that was up pacing at night, he was also not eating, he was actively stressed, so just kind of added to his case that like, this is the whole – you know, it gave us a better picture of whats happening and so being able to see that 12-hours of him that we dont see." Although this particular dog was eventually released from the training program, P2 still found the information provided by the wearable to be useful and was glad that staff were able to intervene.

5.2.6.3 *Prediction & Prevention*

One of the hypotheses that drove the creation of this study was around the ability of activity level to be a predictor for dog job placement. Therefore, the frequency of prediction as a theme was common across the interviews (Table 12). Prediction around what staff expected to see in the data based on what they observed about a dog was also discussed. Individual staff members also shared their hypotheses on what would be discovered as they mined the PAWS data. After viewing some of the data available in the PAWS dashboard, it was interesting to see how staff would alter their hypotheses or remain resolute that they would prove to be correct even when the data they were viewing contradicted them. The flexibility around what could be predictive, and how to identify it, and or modify it can been seen in this quote from P1:

“You know, I think some of it is somewhat predictable, but at the same time, you know, some of the traits we might identify that make dogs better at certain jobs might be related to activity. That they have their innate or whatever they have or develop in terms of their activity that we identify that certain dogs need to be more active. I mean, thats the bottom line”

Discussions around the usage of PAWS to prevent harm, even given the current limitations as it relates to what kind of data it collects, were another unanticipated theme. More details on how this system could be improved so that it is more useful for this purpose can be found in the Information Value and Discussion section.

5.2.6.4 *Wearable Device*

Usability, technical limitations, dog comfort, and dog safety, were themes I had expected based on the anecdotal reports I had received on the wearable device throughout the study (Table 13). The decision to use the Whistle Activity Monitor was one that had been made together with Canine Companions . At the time, it offered the

Table 13: Wearable Device - Discussions on the wearable device used in this study, the Whistle Activity Monitor.

Code	Description	Prototypical Examples
Technical Limitations	Limitations around specific technical issues. Issues in this code would include syncing and battery life.	"Battery life was a big deal and it was one of the reasons we were given for why people dropped out of the study."
Usability	Usability issues separate from technical issues, these include issues like mounting of the device.	"I have strong hands, so it was easy for me. Some of our volunteers are elderly, so it wasn't as easy for them to take the device off and put it back on the collar."
Comfort	Dog comfort as it relates to the wearable device.	"You can tell when the dog isn't keen on it. You see the device gets all scratched up, that's because the dog was trying to get it off in order to be comfortable."
Safety	Dog safety as it relates to the wearable device.	"The worst thing is having to bring a dog to have surgery because they ate the tech. Foreign body problems are real, they should make these things safer."

Table 14: Information value - Discussions around how value is added to the information, through contextual data, level of detail and flexibility of data organization.

Code	Description	Prototypical Examples
Context	Discussions about context of the data influencing the value of the information.	"So what, they had a lot of activity? Well, where was this? If this was a lot of activity at home, ok. If this was a lot of activity because of socialization outings, I'm now much more interested in this. Without context, location specifically, it doesn't matter much to me."
Detail	Desired level of detail in order for the information to have value.	"I need to know what specifically this dog is doing. Walking and running are a good start, but what I really want to know is about the kennel vice behaviors and stuff like scratching."
Organization	How the data organization, and ability to change this affects the information value.	"If all I am seeing is a list of serial numbers, this data does not have a lot of value. It has to be organized in a way that is good for us, not for the makers of the activity monitor."

most robust solution, with the best battery life, and the smallest form-factor. Despite, the shortcomings of using this device for this type of study, I still believe that there is enough promise to warrant future research using this wearable and others. Future researchers are advised to learn from some of our challenges as it pertains to wearable devices to gain a better picture about what limitations may arise when you have a large number of participants many of which are unfamiliar with Bluetooth and IoT technologies. Additional discussion on the technical limitations, specifically as it relates to the wearable device is found in the Discussion section.

5.2.6.5 Information Value

The three areas where staff said more value could be added to the information was, context, detail, and organization (Table 14). Activity data alone is not enough, context is key. In particular location, which was something we saw echoed in the interviews. We also saw an interest in not only know about the level of activities but what specifically those activities are, particularly when it pertains to "kennel vice" behaviors like flank sucking, pacing, and spinning. The theme of the information having value only when it was organized in a useful way was also dominant in the interviews. As P1 stated (condensed): "I just sort of think, as you try to incorporate more data, obviously the ability to just, you know, process it is just the size of it is such that its I think, visually, really difficult to, you know, to to glean this much information from it. I think just thinking about different groups that might you know, the variety of people that might be looking at this, I think that would be a little bit less meaningful to some of them. Or just a little more complicated for them to to glean a lot of information from." Despite the limitations in the level of detail and contextual information that was gathered during the study, staff indicated that they would continue to use the system for future studies and augment the areas of context with an additional tool.

To summarise, the contributions of this research are:

- A data set on working dog puppy movement and rest patterns collected from IMU data from 8 weeks to 18 months of age.
- Design of Puppy Accelerometer Data for Working Dog Suitability (PAWS) system.
- A statistical and qualitative analysis of PAWS for the purpose of working dog training outcome prediction.
- Discovery that activity data alone, as collected in this study, is not predictive of working dog outcomes.
- An analysis of the influence of PAWS on dogs in working dog training environments and of their assessments by working dog practitioners.
- PAWS is useful for monitoring the dogs under working dog practitioner care.

5.2.7 Study Limitations

The method of data collection used in this study has limitations built into it. These study limitations are largely centered around the usage of the wearable device and the lack of information about the environment the dog resides in. Because the goal was to create a method of collecting data that did not rely on self-report, only used sensing technologies on the dog, and provided the ability to view the data remotely, we encountered several technical challenges. If the volunteer did not charge the device regularly, there would have gaps in the data. If the volunteer did not remember the device on outings, we would not have a complete view of that dog's day. Even with perfect use of the wearable device, we still did not have contextual data, nor information on what the habits were of the caretaker. This raised questions specifically around what the activity data from the dog actually tell us. For example, does this low level of activity indicate that this dog prefers to spend most of his day resting, or does this indicate that the caretaker had the dog in a crate for an extended period of time? As remarked upon in the interviews, some staff indicated that they were not sure they believed the activity level indicated in PAWS was "true" considering that so much of what the dog does is dependent on the caretaker.

In addition to this limitation, there is also the issue of dog safety concerns making a dog ineligible to wear the device. If a dog were to chew the device or display discomfort while wearing it, they were removed from the study. Some staff indicated that they were concerned that by making these dogs ineligible to wear the device, they were removing dogs that might have had activity indicators that would turn out to be predictive of their eventual jobs. Anecdotal reports suggested that the dogs likely to chew the wearable were also the same dogs that were activity outliers, however, we were unable to keep the device safely on the dogs long enough that we could gather significant data on their activity habits.

Volunteers who withdrew from the study might also have provided predictive insight. There has not been enough probing into the specifics of why volunteers withdrew, but some staff believe it was primarily due to technical limitations and that the data on their dog care-taking habits may have added significant value to the study if they had been able to continue. This is particularly the case in the success rate of veteran volunteers and the overlap of this demographic with those that are more averse to new technologies.

5.2.8 Discussion

When I reflect on this study and on ways in particular it could be improved, I am left with a list of everything I wish we had done. This list might be unfair to the 2014 version of me, but for the sake of helping future researchers plan their studies, I share it now:

- Ensure your device is durable enough to withstand being chewed on repeatedly by a dog.
- Capture location information alongside activity. This can be done without having GPS in the dog's device, but by using the location of the paired smartphone.
- Hold an in-person, or video chat, orientation with study participants. During this orientation, have participant's pair the devices and connect to a Wi-Fi network.
- Create a new email account that will trigger a help desk ticket for all participants to use for support during the study.
- If multiple dogs will be housed in a kennel for the study, set up Wi-Fi access in that location.
- Before you select or build the technologies you will use for the study, confirm with your partners at the organization what kind of data needs to be collected.
- Design and deploy the visualization platform for the data prior to the end of the study.

- Hold monthly sessions with groups of participants to address any question and capture their ideas.
- Batteries will almost always need to be recharged, so make the process as simple as possible and provide the participant coordinators an easy way to monitor the battery life of multiple dogs at one time.

By integrating the above, I believe a study like this can run much smoother with less demand on the organization staff.

5.2.8.1 Technical Limitations

Technical limitations, specifically around pairing the devices with phones, charging, and using the companion app abounded during this study. During the interviews, one staff member in particular felt like most of her time was spent troubleshooting Bluetooth connections that it became a significant time burden. The most common complaints as reported to staff were the battery life of the wearable device, the impact that pairing their phone with the device had on their own phone's battery life, and the difficulty in removing the wearable device from the collar.

Including the difficulty of removing and mounting the wearable on the dog's collar, the other complaints around the industrial design of the wearable centered on the material choices and what they meant for the durability of the device. The front of the Whistle Activity Monitor has a metal plate which was designed to deter dogs from chewing the device. While the metal was undesirable for chewing, the reflective surface, in the words of one staff member acted "like a beacon" and attracted the attention of the dogs. This metal plate is glued onto the device which is made up of plastic. Once a dog removes the metal plate, the device becomes cracked after the dog chews on it and it renders the device non-functional. If the dog is interrupted while chewing on the device, typically they have managed to break the plastic button on the top and remove the metal plate. Removing the metal plate does not render the device unusable, but breaking the plastic button which is used for manual sync and resetting functions does. Staff estimate that they lost over 20 devices based on the non-functional button alone. Thanks to the support of Whistle Labs, replacement devices were supplied for the duration of the study. However, Canine Companions staff expressed regret that the Whistle Activity Monitor was not more durable. One staff member compared the Activity Monitor to another wearable device they had used for a previous study. That device was much larger and heavier, therefore making it unsuitable to be worn by puppies safely, but they had no incidences of a dog breaking it.

Of course, of greater concern is the safety of the dog that is chewing on the wearable device. Despite multiple incidence of dogs ingesting part of the device, only one dog required surgery, and it was due to the material that the collar the device was on was made of. This nylon material separated in the dog's body and caused a foreign body obstruction which had to be surgically removed.

5.2.9 Conclusions

Despite the technical limitations and resource challenges of this study, I, along with the staff I interviewed at Canine Companions , do believe the research was worthwhile. Although we did not discover predictive indicators, knowing that the way that we measured activity and rest was not predictive is still a result. The dataset that has been generated is of value to them and will continue to be explored internally at CCI. Canine Companions is also planning to use the system for future studies. This use of the system to me is the biggest validation. That Canine Companions would use what we created, PAWS, to run their own independent studies is truly the best outcome I could have hoped for as it means we created something workable and useful.

CHAPTER VI

REFLECTION

To write this chapter, I drew from four years of observations about how people study and design for dogs. These observations occurred during my academic work as well as of my internship experience in multiple industry settings. I have also drawn from my work as a participant-observer volunteering as a puppy raiser, a volunteer at Fulton County animal shelter, and my work as a certified professional dog trainer (CPDT-KA).

6.1 Ethics

As with many interactions involving multiple species, ethical issues in Canine– Centered Computing and the broader field of Animal–Computer Interaction are numerous. These issues range from questions of whether animals should be used in research up to questions of privacy implications of the data that we collect on animals, and by proxy, those the humans they live with. The issues described in this section do not encompass all current and potential ethical issues, but are a selection of issues that are frequently discussed both inside and outside of these research communities.

6.1.1 Consent

One of the biggest challenges in research with animals is how to garner consent. How do you determine if the animal is consenting, assuming their human companion has already given their consent? In my work, I have taken the dog's attempt to distance themselves from the equipment or the researcher to be their withdrawal of consent. From these best practices, a framework for gauging consent, popularized by Clara

Mancini, has emerged.She divides consent into two categories: mediated and contingent. Mediated consent is when the human caretaker for the animal provides their consent, and contingent consent relies on the animal's continued voluntary engagement with the system [73]. In Greg Berns research with awake dogs in an fMRI, he determines ongoing consent by training dogs to voluntarily enter the fMRI and allow them to leave the machine should they wish [16].

6.1.2 Privacy

Another major issue revolves around privacy, the privacy of the animal and that of the humans in the animal's life. Issues of privacy in wearable computing, as they relate to human-worn wearables, are a well-researched area. While on its face, dog-worn wearables do not share the same issues, privacy concerns still remain [132]. One way in which a dog-worn device can have privacy implications for a human is that most of the dogs I have studied spend the majority of their time in the company of humans, and data on the dog's habits ultimately reflects on the human's habits. This window into people's lives through their dog's life is not often discussed in research and should be explored further.

Genevieve Bell has suggested that the technology systems we deploy on animals often serve as augury for human IoT development [11]. If so, there should be additional cause for concern with regards to data usage and privacy. If the current state of data usage with animals predicts similar uses with humans, fitness tracker data would surely be shared with health insurers, healthcare providers, retail stores and dining establishments.

When discussing an animal's own right to privacy, recent work by Brett Mills frames the use of new technologies to overcome an animal's desire not to be seen as largely an issue of 'speciesism;. He says, "'speciesism which affords humans a right to privacy while disavowing other species such rights is one of the tenets upon which humanity's perceived right to maintain mastery over other species is itself maintained [81]."

6.1.3 System Engagement

My research in this dissertation does not contain work with livestock. Because of this, I have not had to tackle the ethical issues directly that some of my ACI colleagues have expressed concerning slaughterhouses. Mancini, in writing on this particular issue, places the decision on which systems to engage with on the individual researcher's ethics: "The way in which ACI researchers negotiate the ethical boundaries between their research and the systems in which their research might take place (e.g. farms, laboratories, zoos) is likely to depend on their knowledge and value system. As an extreme example, some ACI researchers might be willing to design digitally enhanced slaughterhouses to reduce farm animals' suffering at the time of slaughter, while others might not be willing to design technology whose very purpose is to kill animals, although ultimately, this decision on whether or not to work with specific collaborators does come down to the individual researcher's ethics [73]". Despite not working within a research space that directly seems to harm a dog's welfare, I have had an opportunity to question my involvement as a researcher in the law enforcement space. My personal ethics do not allow me to universally condone all actions conducted by law enforcement, but I feel that by engaging as a researcher in these systems I might be able to help improve the welfare of the dogs that work within them, even if I do not agree with all of the jobs that these dogs are asked to do.

6.1.4 Training Considerations

Despite not violating basic tenets of animal welfare, it is still possible to inadvertently 'do harm' to dogs in one's study [27]. In a working dog scenario, this can be done by interfering with the dog's ability to do their job. This interference could be caused by specialised training needed for Canine Centered Computing research over-riding previous training in a dog's job. It is imperative that researchers be sensitive to the essential skills that working dogs perform and consider the implications of having this dog participate in their study. One way to potentially mitigate this issue is by training dogs that are not active working dogs, for example, pet dogs or released working dogs, before selecting working dog participants.

6.1.5 Wearable Technology as Relationship Change Agent

One of the core tenets of this dissertation is that wearable computing systems can improve information asymmetry between dogs and people. With this in mind, I would be remiss to not reflect on the implications of such changes. As stated in the beginning of this document, the relationship between dogs and people is one of the oldest and is incredibly unique. The co-evolution, the so-called "domestication," is unlike any other relationship between two species. We live, work, and often play together, and while this is partially true with other species, there are none which fulfill all of the criteria that dogs do.

That this relationship is important, there is no doubt, as there is also no doubt that it is highly unequal. The methods and tools for interaction between these two species largely derive from a human need to have the dog perform a specific task. The jobs that dogs do that have been featured in this dissertation also fall along these lines, with service dogs being bred for the specific goal of assisting humans. These dogs were not asked to be born into this specific job, and in many organizations, they are also not given an opportunity to "fail" at these jobs until they are almost two years old. While it is true that service dogs do enrich the lives of those they assist, how often do we consider what this means to the life of the dog? Do we infer that those that make it through the service dog, or police dog, training process have an inherent desire to do this job? Or is it enough that they are bred with a goal of being employed in these fields that we, as humans, can assume they want to do them?

What originally drove my exploration in using wearable computing systems for matching the dog to the job was a hope that this would better reveal a dog's own interest in a given job. The puppy I was training, Manolo, also helped to provide a very real example of a dog that seemed to have more of a desire for running on the beach and chasing birds than he did for pulling a wheelchair. I had hoped that if there was a way in which I could quantify, through movement data, the temperament or "personality" of a dog that is poorly suited for a given job, then I could save the dog the stress of being trained for a job that they might not want to do. Without being able to read the canine mind, the best I thought I could hope to do was to draw from how the dog behaved to indicate their desire or willingness to do a specific job. Since so much of canine behavior, and the aspects specifically humans discuss as being more or less suitable, are driven primarily by activity, this seemed to make a compelling case for the use of wearable computing systems. My hope was that through the use of wearable computing systems I might be able to improve dog agency while at the same time assisting a non-profit in their goals of training and placing service dogs.

Despite not finding the clear links between levels of activity, rest and job outcome, the PAWS work has helped to make visible aspects of these dogs' lives that were previously less visible to the caretakers and organization. An example of this is showing how a dog spends the time when they are unobserved. Is the dog pacing, unable to relax, or showing signs of anxiety during this time? Or is the dog taking the opportunity to nap or play? While imperfect, we can take the signs of anxiety during the training period to mean that this dog does not wish to be trained for this job. With the PAWS system, this pacing, when the dogs had been assumed to be resting was evident. The caretakers could ignore this information being provided by the wearable computing systems and continue on their predefined training course, but clearly there are ethical implications. To ignore the now visible signs of distress is to ignore an important component of this dog's welfare. By making this information clear and visible, it encourages change.

The wearable computing system acting as an agent of change is not restricted to the working dog domain. In the work with the Humane Society, we saw a similar potential for the wearable computing systems to alter the relationship between humans, dogs in the shelter, and those newly adopted. In this study the result was positive, with the new information being provided to humans increasing their desire for adopting particular dogs and of spending more time with them.

What are the implications of these changes? In these early days, the implications have been largely manifest as an improvement in the welfare of the dogs. While my hope is that the changes will always be positive, it is reasonable to assume that this might not always be the case. A possible negative outcome would be a dog's history of undesirable behaviors hindering their ability to find a new home. While these behaviors might not manifest themselves in a different context, many adopters could find the history of them to be discouraging. This is just one example of the potential of the technologies described in this dissertation to harm dogs instead of help them. Despite this drawback, it is my desire and hope that the benefits of such technologies will prevail and the changes that happen in the relationship between dogs and people will be as beneficial for dogs and humans.

6.2 Design Considerations

In the course of my research at Georgia Tech, and my work as a Research Scientist at Whistle Labs and Intel Labs, I have had the opportunity to design multiple wearables for dogs, several of which have been featured in this dissertation. To paint a picture of this design process as a linear process would do a disservice to the experience and the dogs. Designing, prototyping, testing, and conducting field studies with dogs is, like many studies in the wild, inherently messy. These reflections are by no means the complete treatise on what designing for dogs entails, however, they are pieces of what I have learned during this process.

6.2.1 Diversity

Designing for dogs, like all user–centered design, requires knowledge about the user. The main difference between designing for dogs and desiging for humans, is the diversity inherent in the species itself. For example, the differences between a Chihuahua and a Great Dane contradict the notion "one size fits all". In addition to the size differences within groups of dogs, each dog, like each person, is an individual. What one dog might find comfortable, another could find bothersome. While there are specific materials that are known to be uncomfortable for dogs due to their type of coat, there is a prototyping process that is necessary and involves a good deal of testing with the dog(s) we are designing for. I situate my design process primarily within a user–centered design framework. I begin with observations in the field, and my frequent tool for analysis of these observations has been Distributed Cognition. Although I do not consider what I have presented in this dissertation to be the work of exclusively co-designing with dogs, I have found design probes with people as well as dogs to be helpful [74].

How then, do you gather the input from a dog? There are multiple ways to do so. First consult the relevant literature. As mentioned in the related work, veterinary, animal behavior, and canine cognition literature provide guidance in regards to the physical constraints such as which colors dogs can see best, and other limits of canine perception [87, 50]. After ensuring your prototype respects canine capabilities, you can begin soliciting dog-specific input. Like mediated consent, one approach is to ask the human companion of the dog for what they think their dog will respond or prefer.

Another route is to provide the dog with multiple options and the opportunity to interact with them while being observed. Ordering effects will confound this, so be sure to use a Latin Square design to counterbalance these effects. This method also works well for assessing wearable fit preference. As with all testing with dogs, assessing canine body postures (this includes panting and tail tucking) is important as a potential indicator of stress or discomfort. Posture is particularly salient when assessing something that is worn on the dog.

6.2.2 Interaction

Dogs, like human infants, will, if given the opportunity, often put novel objects into their mouths. Dogs might also break apart a new prototype intentionally or unintentionally. In addition, behavior that a human might view as destructive (e.g., shredding of an object) might in fact be a coping mechanism in a stressful situation [105]. Dogs have demonstrated a preference for textures that afford chewing, even over more rigid structures that make noise [126]. This preference is important to note not only when designing a toy or an object for them interact with, but also for designing items the dogs should not interact with. Better interaction affordances often come with tradeoffs of robustness and ease of cleaning. Pullen et. al summarizes robustness tradeoffs as "easy to clean and relatively indestructible, may concomitantly reduce the very features that stimulate interactive play [97]."

For example, if a dog is likely to chew part of a prototype, will that prototype remain useful? Anticipating future uses of the device, outside of what it was originally designed for, makes a compelling case for meta-design, "designing for after design", as a potentially useful approach when designing for dogs [32]. Could we design a system that remains useful to dogs after they have interacted with it in such a way that its original use no longer remains? I am interested to see meta-design applied to Canine Centered Computing because, unlike aspects of participatory design described by Ehn, the research community has of yet to explore this [74].

6.2.3 Safety

Last, but certainly not least, is safety. There are currently no international standards regarding computing devices worn by dogs. However, I have found the following standards relating to the safety of toys to be helpful. Additionally, I have listed three publications about substances toxic to dogs that are an important reference when designing devices that the dog might chew or ingest:

- ISO 8124-1:2014 provides good safety guidelines related to mechanical and physical properties.
- ISO 8124-5:2015 - for determining concentration of elements that could be harmful if ingested.
- Eriksen et.al, Campbell, and Cope provide a good supplement to ISO 8124-5:2015 that is specific to canines. [34, 22, 25]

To address the gap left by the lack of specific safety standards, I began formulating my own requirements based on discussions with veterinarians and working dog handlers. Here is my list of computing device safety considerations when designing for dogs:

- Device must be able to withstand 500 psi of pressure without breaking open (This is average max jaw strength of large dog).
- Device should not be able to be removed from collar through pulling (160 newtons of force).
- Device must be non-toxic and radio-opaque (meaning it would show up on a radiograph).
- Device should not be more than 1.5 in length, width, or height to prevent becoming a bowel obstruction (for a medium-large-sized dog).

- Device should not weigh more than 1.2 oz for a medium sized dog.
- Device should be water-resistane and any ports should be protected against both moisture and dog hair.
- Device should be able to be cleaned with water, soap, and vinegar.
- If the device is to be worn in a kennel or X-Pen or while dogs are co-housed, the collar or harness should be a break-away design to prevent strangulation.

While this list is by no means exhaustive, I hope it will service as useful guidance for those looking to design computing technologies for dogs.

6.3 Future of Canine Centered Computing

Where does this field go? Will Canine Centered Computing (CCC) as a research area be eclipsed or carried out exclusively in the industrial domain? Or, are the recent flood of dog technology related startups yet another fad? As a researcher in this space I have a vested interest in seeing research continue as well as interest in industry. There is the potential for a decline in commercial interest in dog wearables as the public continues to lose patience with unfulfilled promises. This is not unlike the trends that we see commercially in human-worn devices. These trends do not mean that all wearables are dead forever, but that there is room for improvement in their capabilities, form-factors, and accessibility of these devices for both humans and dogs. I believe that the CCC and ACI research communities have much to contribute to the continued commercial development of such technologies. They can also add to their respective bodies of knowledge in addition to those in the veterinary and canine cognition spaces.

Improved physiological monitoring, assessment of stress and anxiety, instrumented toys, and dog–human communication, are all areas where CCC is well positioned to explore. In addition to these areas, I exhort future researchers in this space to not neglect field work and testing in-the-wild. Since dogs are highly contextual, it is important to observe them where they will be utilizing the technologies researchers develop. Testing in-the-wild, while more logistically challenging than testing in a laboratory setting, is vitally important for this type of research. This importance only increases when working closely with collaborators outside of the computing domain, particularly those at non-profit sites. Testing in-the-wild will provide insight into the potential workability of the solution that is being tested which is of critical importance to these sites.

Building strong collaborations outside of computing, in particular with animal welfare and veterinary practitioners is key. As the fields of ACI and CCC mature, we have seen an increase in such collaborations. I strongly believe that these collaborations are integral if these research fields wish to grow and have an impact on the lives of dogs.

CHAPTER VII

CONCLUSION

In conclusion, I have addressed my research goals through a series of prototype systems and reflection on such systems:

1. Create new modes of dog–human interaction with wearable systems.
2. Design systems and actions that support these interactions.
3. Improve the information flow in dog–human interactions through wearable systems.

To examine my proposal that wearable systems can support short-term interactions for communicating a specific message, long-term interactions for monitoring and interactions for collaboration, and address the first research goal, I described *Descriptive, Diagnostic and Directive* interactions that are facilitated by wearable computing. *Descriptive* interactions allow dogs to send a specific message to humans. *Diagnostic* interactions allow humans to understand canine actions on a broader scale. Finally, *Directive* interactions support decision-making in collaborative canine–human systems, such as explosive-detection teams.

My second research goal, focusing on the design of such systems is primarily addressed by work found in the *Descriptive* chapter, although there are systems that support this question also found in chapters four and five.

For my third research goal, my proposal was that wearable systems could increase the quality, quantity, and accessibility of information as well as the number of recipients of that information. This research goal is addressed by work found in the *Diagnostic* chapter and *Directive* chapter.

As promised, my dissertation did not create a love–detector or dog–thought–decoder, but I have shown practical ways in which the information asymmetry between dogs and humans can begin to be addressed. This dissertation, while one of the first in Canine–Centered–Computing, will hopefully not be the last and I look forward to continuing work in this space.

APPENDIX A

RESEARCH OVERVIEW

Research Goal		Data Source	Results
1. Create new modes of dog–human interaction? with wearable systems.	A. Wearable systems can support short-term interactions and long-term interactions for monitoring B: Wearable systems can support interactions for collaboration	Descriptive: Wearable Alert System for Service Dogs Gesture-based Alert System for Service Dogs Diagnostic: Increasing the Permanent Adoption of Shelter Dogs Restfulness and Dog Training Outcomes Directive: Mobile Collaboration for ED Teams PAWS	Wearable systems can create three types of interactions. These are descriptive, diagnostic, and directive.
2. Design systems and actions that support these interactions.	A. The design should be created alongside practitioners in the system domain. B. Wearable systems for dogs should use the minimum amount of equipment and not limit their movement. C. Distributed Cognition and Contextual Design are useful tools in designing systems that supports humans and dogs.	Wearable Alert System for Service Dogs: Observations Computational artifacts Quantitative study of interface activation (3) Canine Reachability Quantitative study of dog on-body, interface reach (6) Gesture-based Alert System for Service Dogs: Interviews Observations Quantitative study on dog gestures (2) Post-study reviews with collaborator Mobile Collaboration for Explosive Detection Teams Interviews (4) Observations (25) Computational artifacts Post-study reviews with participants	Wearable Alert System for Service Dogs: An adaptable, balanced-weight design increased overall reachability from 86% to 91% (and from 40% to 91% in participant with lowest results in previous study). Detection accuracy rose from 60% to 91%. Canine Reachability: Side placements are less directed and require more effort than placement on front legs. Placements past the ribcage were comparatively inaccessible. Gesture-based Alert System for Service Dogs: The four gestures selected could be reliably performed, detected with 75-100% accuracy and a false positive rate of 0.4/hr. Mobile Collaboration for ED Teams Used Distributed Cognition to understand challenges and breakdowns. Used Contextual Design to create a prototype system The mapping interface with collaborative annotation and scent alerts was universally valued by the officers
3. Improve the information flow in dog–human interactions through wearable systems.	A. Wearable systems increase the quality and quantity of information in a kenneled and home environment. B. Wearable systems increase the number of recipients of information in work environments. C. Wearable systems increase information accessibility in kenneled and home environments.	Increasing the Permanent Adoption of Shelter Dogs: Pre+Post Demographics During & post-study surveys Observations Computational artifacts Post-study reviews with collaborator Workability of solutions as measured by community collaborator Mobile Collaboration for ED Teams Interviews (4) Observations (25) Computational artifacts Post-study reviews with participants Puppy Accelerometer Data for Working Dog Suitability Interviews Observations Computational artifacts Quantitative outcome study driven by CCI research questions Post-study reviews with participants Pattern coding of qualitative data to find themes Statistical analysis of quantitative data 'Workability' of solutions as measured by community collaborator	Increasing the Permanent Adoption of Shelter Dogs: Lower rate of re-relinquishment (returns) in the experiment group. The rate of re-relinquishment for the experiment group was 6.25%, and control group 12%. 67 % of the one-week and 60 % of the one month respondents indicated that they found the information provided in the application helpful Mobile Collaboration for ED Teams The mapping interface with collaborative annotation and scent alerts was universally valued by the officers. They expressed that this technology allowed them to coordinate searches better than using radio transceivers, which were often not universally accessible. PAWS Activity and Rest were not found to be predictive of dog training outcomes. System provided an increase available info about a dog and the number of info recipients.

Table 15: Research Overview

APPENDIX B

API OVERVIEW

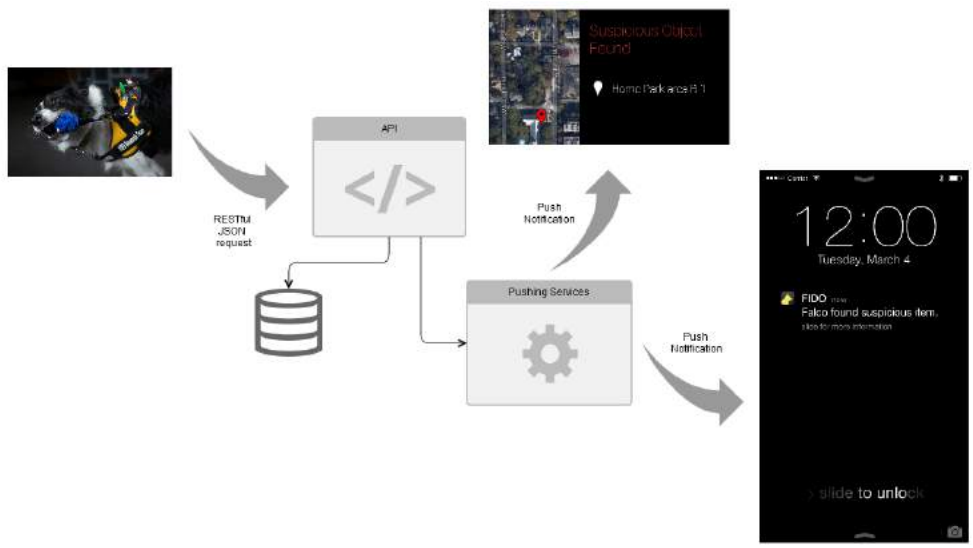

Figure 31: Police System API Overview.

APPENDIX C

INTERVIEW GUIDE

Staff Interview Guide

Georgia Institute of Technology
Project Title: *Technology Use with Service Dogs*
Investigators: *Dr Melody Jackson, Joelle Alcaidinho, Michaelanne Dye, Giancarlo Valentin, Thad Starner*

Our interview will follow a semi-structured format in which we follow up on what the participant says. General topic areas are:

Interview Guide

- Basic demographic information
- Experiences with service dogs (e.g. when did they first become involved with Canine Companions, have they ever raised a service dog for another organization)
- Experience with dogs, both pet and working.
- Description of their job role and current usage of technology within that role.
- Your practices (and those of your community) surrounding Canine Companions volunteering and work
- Current process of gathering information on the CCI dog they are working with
- Changes in perceptions, relationships with the dogs participating in the study
- Other information sources used in their job at Canine Companions
- Other useful tools/technologies/networks
- Questions regarding usage of the Whistle Activity Monitor:
  - Ways in which they the Whistle Activity Monitor, app and/ or data spreadsheets
  - The benefits and disadvantages of the Whistle Activity Monitor
  - If/how they shared the information they received from the device with others
  - Plans for continued use of the device and app
  - Ideas for improvements
  - Satisfaction with the device and app
  - Sustainability of using this device to collect data (thoughts on whether others would be interested in using it, if it would be helpful, etc.)
  - Did their views or opinions on specific dogs change as a result of using this device and app?
  - Changes in their work practice through the usage of the activity monitor
  - Changes in their communication with puppy raisers due to the device
  - Comparison of communication practice for dogs with the technology

Figure 32: Staff Interview Guide.

APPENDIX D

CODEBOOKS

Theme	Code: parent	Code: child	Definition	Notes
Usability	PAWS System usability	Device usability	Comments about the ease-of-use of the puppy wearable device	Could potentially be divided into puppy-raiser and staff usability
Usability	PAWS System usability	App usability	Comments about the ease-of-use and user interface of the wearable companion app	Could potentially be divided into puppy-raiser and staff usability
Usability	PAWS System usability	Desktop usability	Comments about the desktop app	Could split into spreadsheets and live-web view
Usage	System Usage	Puppy-raiser system usage	Comments about how often and why the system was used by puppy-raisers	May include discussion of challenges that prevented frequent usage
Usage	System Usage	CCI Staff system usage	Comments about how often and why the system was used by CCI staff	May include discussion of challenges that prevented frequent usage
Puppy Care	Puppy Caretaking	Puppy-raiser caretaking	Comments about caretaking of puppies with and without the system by puppy-raisers	May include discussion of care of puppies prior to the study
Puppy Care	Puppy Caretaking	CCI Staff caretaking	Comments about caretaking of puppies with and without the system by CCI Staff	May include discussion of care of puppies prior to the study
Sense-making	Data analysis	Single dog data sense-making strategies	Comments about sense-making techniques used in viewing data on a single dog	Could be split into app and desktop discussion
Sense-making	Data analysis	Multiple dog data sense-making strategies	Comments about sense-making techniques used in viewing data on multiple dogs	Could be split into app and desktop discussion

Figure 33: Anticipated Codes.

Code Name		Description	Prototypical Examples
Data Access: The dog wearable is continuously collecting data on the dogs. This code concerns access discussions and decisions around the control of these data.	Sharing	Sharing of the data	"I would like all of the regions to be able to see this."
	Privacy	Privacy of the data	"Even though it might be good to see the data and check-in with the volunteers, I'm worried it might be seem like an invasion of privacy."
	Control	Who owns the data and who sees this data	"But I'm just careful who has access to that data, because I don't want at this point any decisions made about a dog just based on what they see. You have to be careful who sees what."
Dog Health: Physical and emotional health of the dog. Viewing key indicators of health in the PAWS mobile application as well as discussions of these data with the dog's caretakers.	Overall Activity	Viewing the activity levels of a given dog.	"Seeing these overall activity levels is like having an opportunity to kind of observe a dog over time and you're not limited to a snapshot. You really get a more complete picture of their health."
	Exercise	Viewing and discussing the amount of exercise a dog receives	"I think it is something we need to look into, the exercise levels of the dog and how this impact their health and performance in the program."
	Rest	Viewing the rest or sleep data on a given dog.	"Some of the most interesting things we saw was around sleep. Are they getting enough rest at night?"
	Energy Level	Discussing the perceived energy level of a dog as compared to others.	"We tend to put dogs with higher energy levels into specific job categories. A higher energy dog might not be right for any of our jobs."
	Stress	Discussing the perceived level of stress a dog is experiencing and ways to intervene	"Although we aren't getting a measure of stress directly from the PAWS tools, I like to look at what the dogs do in the evening to see if they are able to rest, instead of pacing, having high activity at night, which is a sign of stress."
Prediction: Predictions made among the staff as it relates to dog suitability, dog	Dog Suitability	Ad-hoc discussions or decisions made	"One of the things we are interested in trying to predict is if we look at the dog's activity and we know their

Figure 34: Codebook Page 1

expectations, and hypotheses of what they expect to see in the data.		about the suitability of a dog for a given job.	outcomes, could we have matched them just using the activity to determine dog suitability?"
	Dog Expectations	Predictions made a-priori on what to expect from a specific dog.	"We knew to expect a lot of energy from this dog based on what the volunteers said in their monthly reports. I personally did not really expect the dog to make it successfully through training."
	Hypotheses	Hypotheses on the predictive properties of the data	"I have a few ideas about what is going to be important in this set of data, I think rest and activity are likely to be the most predictive."
Preventative: Data from the system being used to prevent harm and improve outcomes. This code can be used when speaking about the current usage of the system to facilitate these items and not when speaking about desired or future technology.	Prevent Harm	Data used to prevent harm	"If I could know when the dog is flank sucking before I see the signs on their coat, I could treat it and deploy an intervention."
	Prevent Training Failure	Data used to stage an intervention that attempts to improve the dog's training outcome	"Well, I have always thought that dogs who don't get enough sleep at night perform worse in training...so when I saw this dog wasn't sleeping, I tried changing his kennel in order to give him a better chance of training success."
Study Logistics	Data Collection	Logistics of the data collection	"Just getting everything out to the volunteers and then to the regions so they could collect the data was a logistical hurdle. I really underestimated that."
Ideal Technology: Future technology wish list and discussion of ideal technology for the environment.	Wearable Device	Descriptions of an ideal wearable device and sensing technologies	"I really want to see heart-rate and respiration. Also it should give me more information, or any information really on stress. That matters more to me than exercise."
	Companion mobile app	Descriptions of what is desired in a future companion mobile app.	"For a setting like ours we need to be able to see multiple dogs at once. Like being able to know who is syncing and who isn't without going into each dog's account is a must."
	Companion Desktop App	Descriptions of what is desired	"When I think about what I want to see on my office computer, I think about

Figure 35: Codebook Page 2

		as it relates to viewing the data on a desktop computer.	charts, these really nice charts, that show me all my dogs in this region."
Information value: Discussions around how value is added to the information, through contextual data, level of detail and flexibility of data organization.	Context	Discussions about context of the data influencing the value of the information.	"So what, they had a lot of activity? Well, where was this? If this was a lot of activity at home, ok. If this was a lot of activity because of socialisation outings, I'm now much more interested in this. Without context, location specifically, it doesn't matter much to me."
	Detail	Desired level of detail in order for the information to have value.	"I need to know what specifically this dog is doing. Walking and running are a good start, but what I really want to know is about the kennel vice behaviors and stuff like scratching."
	Organization	How the data organization, and ability to change this affects the information value.	"If all I am seeing is a list of serial numbers, this data does not have a lot of value. It has to be organized in a way that is good for us, not for the makers of the activity monitor."
Surprises: Unexpected data, dog behavior, and events during the study.	Data	Surprises in the data during and after the study.	"I knew the dogs were wearing accelerometers, but I don't think I really knew what that meant...when I saw the data, I was surprised at the sheer amount of it."
	Dog Behavior	Unexpected dog behavior during the study.	"Few people thought the issue of dogs eating other dog's wearable would be this big of a deal. They couldn't resist!"
	Study	Unexpected events during the study.	"We didn't think we would really look at the data while the study was happening, outside of checking for syncing. I did though. I saw one dog in particular who seemed to not be adjusting, so I used the data to have a conversation with his caretakers."
Analysis: Discussions of the tools and process of data analysis.	Sensemaking	Extracting meaning from data	"I need to slice and dice the data, organize it in a way it makes sense to me. Otherwise, it can be pretty

Figure 36: Codebook Page 3

			meaningless."
	Visualizations	How the data is visualised.	"Without being able to see the clusters, it is hard to grasp... it is why I really like scatterplots."
	Comparisons	Comparisons with the dataset and with external data.	"One of the things I want to do is compare this dog's trends with what the volunteer said about them, also the genetic data too."
Wearable Device: Discussions on the wearable device used in this study, the Whistle Activity Monitor.	Technical Limitations	Limitations around specific technical issues. Issues in this code would include syncing, battery life.	"Battery life was a big deal and it was one of the reasons we were given for why people dropped out of the study."
	Usability	Usability issues separate from technical issues, these include issues like mounting of the device.	"I have strong hands, so it was easy for me. Some of our volunteers are elderly, so it wasn't as easy for them to take the device off and put it back on the collar."
	Dog Comfort	Dog comfort as it relates to the wearable device.	"You can tell when the dog isn't keen on it. You see the device gets all scratched up, that's because the dog was trying to get it off in order to be comfortable."
	Dog Safety	Dog safety as it relates to the wearable device.	"The worst thing is having to bring a dog to have surgery because they ate the tech. Foreign body problems are real, they should make these things safer."
Time: Discussions around the usages of personnel time during the study and various discussions around time as a construct.	Staff	Staff time demands during the study.	"I spent so much time explaining Bluetooth. It was like my life for the beginning of the study. It took so much time... why isn't Bluetooth friendlier?"
	Volunteer	Volunteer time demands during the study.	"She said that teaching the dog to toilet outside was time consuming enough, let alone having this extra thing to put on the dog and remember to charge it. It was one more time sink."

Figure 37: Codebook Page 4

	Replacement	Technology used to replace time intensive observations	"What I am so happy about is that I can look at this dashboard and see something that it would have taken an army of grad students hours to observe."
	Dog Time	System data being used to display how a dog spends their time.	"When I ask myself, what does this dog do all day and how has this changed? I now have a better idea, before I had to piece it together from anecdotal reports."
	Data Time	Time between data collection and being able to access the data.	"I think for volunteer homes, if we could see the data once a week that would be fine, but when the dog is in our care, we want to see the data within the hour of when it was collected."
App: Comments about the ease-of-use and user interface of the wearable companion app.	Usability	Usability of the app as it pertains to service dog training goals.	"This app was clearly not made for us. It's impossible to see all of my dogs at once. It's fine for a person at home with one dog, but for an organization like ours it is a pain."
	UI	Discussions about the user interface of the mobile app.	"I would get so many questions about the graphs and why some days the lines aren't as high. Explaining that it is all relative from one day to the next wasn't comforting, it was still confusing."
	Limitations	Data display limitations within the app as well as any technical issues within the app.	"Sometimes it would tell me that I was paired, and I don't think I was... it was like a disconnect between the phone Bluetooth and the app... I never really could tell what was happening at any moment if they really were connected."

Figure 38: Codebook Page 5

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