UbiComp for Animal Welfare: Envisioning Smart Environments for Kenneled Dogs

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ABSTRACT
Whilst the ubicomp community has successfully embraced a number of societal challenges for human benefit, including healthcare and sustainability, the well-being of other animals is hitherto underrepresented. We argue that ubicomp technologies, including sensing and monitoring devices as well as tangible and embodied interfaces, could make a valuable contribution to animal welfare. This paper particularly focuses on dogs in kenneled accommodation, as we investigate the opportunities and challenges for a *smart kennel* aiming to foster canine welfare. We conducted an in-depth ethnographic study of a dog rehoming center over four months; based on our findings, we propose a welfare-centered framework for designing smart environments, integrating monitoring and interaction with information management. We discuss the methodological issues we encountered during the research and propose a *smart ethnographic* approach for similar projects.

Author Keywords
Animal welfare; smart kennel; ambient interactivity; pervasive monitoring; information management

ACM Classification Keywords
H.5.2: User-centered design

INTRODUCTION
Animals are involved in every aspect of human life, from farming to research, from servicing to companionship, and over the centuries the relationship human society has had with other animals has evolved significantly. Since the foundation of the first animal protection organization in 1824 [30] animal welfare has gradually grown as a value in many cultures and an increasing number of scientists have focused on it. Nowadays, many national and international legal frameworks regulating human activity include animal welfare provisions and animal welfare science is rapidly developing [8], consistent with societal growing concern for other sentient beings [45]. A typical consequence of human activity involving animals is their confinement. Around the world billions of animals live in indoor farms, research laboratories, zoos or other confining environments. Thus the welfare implications of providing appropriate, or not, living conditions for confined animals are highly significant. For decades, ubiquitous computing technology has played a role in animal welfare management in various scientific and economic sectors (e.g. telemetry in laboratories [5], intelligent feeding systems in farming [10]). However, the ubicomp community still has to embrace animal welfare as a worthy area of research and design. We argue that this community has an opportunity, and a responsibility, to engage with this underrepresented area of scientific interest, societal relevance and moral stand, and contribute its unique expertise to ongoing efforts aiming to improve the welfare of animals permanently or temporarily confined in the context of human activities or in an attempt to attend to their welfare.

As a catalyst for our discussion on how ubiquitous computing could help support the welfare of managed animals, we focus on the case of dogs in kenneled accommodation. Many dogs live in kennels, for all or part of their life. For example, following socialisation, guide or assistance dogs are kenneled during long training periods prior to being partnered with their assisted humans. Police or military dogs also spend a considerable proportion of their lives in kennels. Additionally, every year, thousands of homeless dogs spend variable amounts of times in kennels waiting to be homed. While many kenneling facilities make every effort to ease the effects of confinement, the necessary constraints of even the best kennel environments make meeting the welfare requirements of kenneled dogs challenging [37]. For example, being small and simply furnished spaces, kennels offer limited stimulation for dogs; for safety reasons, the dogs are not allowed to move in and out of their living quarters at will and circulate freely; where irregularities in management practices occur, they are often unable to predict what is going to happen next and assess whether new events represent a threat; due to the fact that care-taking staff have a number of dogs to look after, individual dogs receive less attention than they would in a home, and out of working hours they may find themselves

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alone. Furthermore, assessing the welfare of kenneled dogs is non-trivial, since the measures that have so far been more accessible are not necessarily the more indicative. For example, carers might be able to observe behaviors which may be difficult to interpret, particularly when monitoring cannot be continuous. Thus, welfare issues, whether pre-existing or induced by kennel confinement, may remain undetected and unaddressed until they become overt and possibly more difficult to resolve.

We wanted to investigate whether recent advances in ubiquitous computing to enhance human wellbeing and daily experience [1] might offer the opportunity to improve how the welfare of kenneled dogs is managed. On the one hand, we wanted to explore whether ubiquitous sensor systems and ambient intelligence developed to monitor health in humans (e.g. activity levels, sleeping patterns [2]) might be useful to record, measure, visualize and interpret non-obvious welfare-relevant phenomena, especially when it is non-viable or non-desirable for individual dogs to receive continuous attention. On the other hand, we wanted to explore whether the use of embodied and tangible interaction technologies developed to enhance human performance and experience (e.g. touch or gestural interfaces [46]) might afford the dogs a more stimulating experience and greater control over their surroundings through forms of interaction that are accessible to them [32]. Here we present our early investigations of a *smart kennel* concept integrating interactive and monitoring technology to improve the welfare of kennel dogs.

As a first step towards such a vision, we conducted an ethnographic study at one of the rehoming centers of Dogs Trust, the UK's leading canine welfare charity. Our aim was to identify core requirements from both canine residents and human carers who live and work in the rehoming center, in order to understand how smart technology could support these users. Here we report on the findings of our exploratory work, challenges we have encountered, and possible solutions we have so far identified, at the design and methodology level. Based on our findings, we propose a 'three-dimensional' welfare-centered framework for designing smart environments, integrating monitoring and interaction with information management, which we illustrate with a scenario. We also discuss the methodological challenges we have encountered during the research and propose a ubicomp-supported ethnographic approach for similar projects.

UNDERSTANDING ANIMAL WELFARE

What welfare is about

Animal welfare can be described in terms of evolutionary adaptation to their living environment [7]. Animals have evolved physical adaptations to cope with environmental conditions (e.g. a thick coat), for exploiting available resources (e.g. teeth and claws) and for recovering from injury (e.g. an immune system), in order to survive and reproduce. Animals have also evolved adaptations for preventing the occurrence of conditions that could compromise their survival in the first place, adaptations which result in the animal wanting certain things as expressed through different behavioral patterns (e.g. roaming in search of food, burrowing for protection). Even in the absence of specific threats or when basic resources are provided, animals still tend to seek information about their environment, which indicates that dynamic and individualized enrichment has an essential role to play within captive environments, i.e. we need to meet animals' 'wants' as well as their needs for good welfare.

For Stamp Dawkins [34] good welfare presupposes the fulfilment of two fundamental conditions: that an animal *is healthy* and that they *have what they want*. A living environment that meets the health requirements of an animal while frustrating their wants (e.g. if a burrowing animal has nowhere to dig, if a social animal is kept in isolation) compromises the animal's welfare, leading to physiological and psychological problems (e.g. self-injury, stereotypic behavior). Sporadic aversive conditions (e.g. a sudden loud noise) may affect an animal's emotional state short term or long term (if the event is deemed important enough by the individual); additionally, protracted aversive conditions (e.g. long periods of isolation) or frequent recurring aversives (e.g. repeated exposure to social isolation for a gregarious individual) will often result in negative mood states in the longer term [21]. Thus the elimination of aversions, particularly chronic ones, from an animals' environment is critical for their welfare. Furthermore, while for a long time animal welfare was rather thought of as the elimination of negative states, in recent years more emphasis has been placed on the achievement of positive states [4]. Thus an animal's living environment should not simply eliminate aversions, but provide conditions that foster positive physiological and psychological states. But how can these states be measured?

Measuring welfare in animals

An animal's welfare may be reflected by a number of indicators, some of which are easier than others to interpret. Pertaining to bodily integrity, indicators of physical health might include freedom from disease or injury, and fitness parameters, such as weight or coat condition, which are comparatively easy to interpret [8,34]. Psychological wellbeing is also an integral part of welfare considerations [23,38]. However, measuring psychological wellbeing (e.g. affect) using physiological indicators is non-trivial. For example, parameters such as heart or respiration rates may reflect arousal but not valence [8]. Accurately measuring parameters which are more indicative of valence may be challenging. For example, intra-aural temperature difference might indicate valence by showing which side of the brain is more engaged in processing a response to a stimulus [47], but measuring it with precision entails the use of obtrusive equipment (e.g. intra-aural probe), which may affect an animal's emotional state and result in data pollution. Behavioral indicators can also be used to measure psychological wellbeing, although again these may be less reliable. For one thing, they may not be overt (e.g. an injured bull might not show any signs of lameness until he is left alone [8]); for another thing, such indicators may be ambiguous, particularly under sporadic observation (e.g. a dog who spends time curled up in his bed may be relaxing or depressed and short term it may not be obvious which is the case); their meaning may not be clear in isolation (e.g. tail wagging in dogs may indicate different moods depending on its amplitude, intensity and lateral bias) or it may be specific to individuals. Researchers often use a combination of behavioral and physiological parameters to infer welfare states [8]; sometimes, they embed monitoring equipment in the environment rather than placing it on the animals, thus limiting obtrusiveness but possibly also sacrificing interpretational accuracy [27]. Ideally, welfare assessment should be based on the integration of behavioral and physiological data which is qualitatively significant, real-time and noiseless, having been collected without impacting upon the animal. But what are the specific factors that influence the welfare of confined animals?

Canine welfare in kenneled accommodation

Taylor and Mills [37] discussed factors affecting the welfare of confined animals with particular reference to kenneled dogs. The authors identified the amount and quality of stimulation, including the opportunity to engage in diverse activities, as one of the key elements. For example, while dogs housed in small barren spaces are inactive most of the time, their activity levels increase with the amount (i.e. dimensions [11]) and complexity of space (e.g. furnishings [12], outdoor access, [19]) available in a positive way. Similarly, providing dogs with opportunities for appropriate dog-dog and dog-human interactions was found to reduce the occurrence of unhealthy behaviors (e.g. stereotypies such as spinning, chasing own tail, self-biting [19]). Additionally, forms of enriching stimulation, such as music [41] or toys [42], were found to improve the dogs' welfare, particularly if the dogs were allowed to physically engage in activities which provided for a level of variation (e.g. as with a toy rotation [42]) and which were biologically relevant (e.g. involving food [11]). Another important element highlighted by Taylor and Mills [37] is environmental controllability. For example, the ability to hide (as a way of controlling access others might have to them) is often beneficial for kenneled animals [24]. Closely related to the issue of controllability, environmental predictability was identified as another key variable affecting kenneled dog welfare by Taylor and Mills [37]. Dogs may be distressed by the inability to predict events in their environment, and thus adjust to it, until they are able to learn kennel routines (e.g. knowing when in the day a meal might come or being able to read carers' behavior as indicating an imminent walk) [36]. These observations point to the conclusion that, in order to support good welfare, *kennels ought to afford resident dogs control over an appropriately rich range of stimuli offering consistent responses to the dogs' choices and actions*.

However, as Taylor and Mills [37] highlighted, knowledge of the welfare implications of the different aspects of the kennel environment has been so far limited by the pragmatic choice of measures which are non-specific to different welfare states (e.g. heart rate or immune function) or which are quantitative rather than qualitative (e.g. amount of activity over quality of activity patterns, i.e. exploring vs stereotyping). *There is therefore the need for interventions which can enable the collection of quantitative and qualitative measures directly relevant to canine welfare states.* If appropriately designed and implemented, such interventions could improve both the welfare of kenneled dogs and knowledge of what exactly affects their welfare in the first place. But what could enable the achievement of such aims?

UBICOMP FOR ANIMAL WELFARE

Ubicomp and quality of life

Advances in ubiquitous computing make it now possible to design intelligent technological interventions to monitor and improve quality of life in humans [2]. Touch-screen [46] and gestural [40] interfaces enable more natural interaction modalities. Smart objects and cybertectures provide adaptive environments which dynamically accommodate our needs. Biometric clothing unobtrusively monitors our health [6] and emotional changes projecting them on the fabrics that envelop our bodies [3]. Wearable EEG technology [14] recognises our mental states thus enabling us to control our surroundings. Could such technological capabilities be used to improve the quality of life in animals living in the confines of built environments? Is there scope for employing these capabilities to enrich kennel environments by affording resident dogs appropriate stimulation and variety as well as control and predictability, and at the same time by monitoring and supporting the interpretation of welfare-salient measures?

In human ubiquitous computing the achievements described above have been driven by what interaction designers call user-centered design [29]. But to what extent could user-centered, participatory approaches be applied to the design of ubicomp solutions for supporting the welfare of animals within environments such as farms, laboratories or kennels?

Designing for animal welfare

The development of animal technology has only recently become the interest of interaction designers, who have begun exploring, within the area of Animal-Computer Interaction (ACI) [16,17], the possibility of developing user-centered approaches to designing animal technology. Particularly relevant here is work that has dealt with requirements elicitation and evaluation aspects.

For example, Resner's [26] early canine-centered design framework for a human-dog remote training system was directly informed by human-centered design protocols while accounting for species-specific physiological and behavioral characteristics. More recently, Jackson *et al.* [13] made similar species-specific ergonomic considerations while developing a tangible, wearable interface allowing search and rescue dogs to communicate with their handlers in the field. However, individual animals present specificities which go beyond their species and which may derive from the animals' breed (e.g. terrier vs Labrador), occupation (e.g. guide dog vs hunting dog) or upbringing (e.g. certain training styles). *Thus how could research frameworks account for the different requirements of individual animals?*

While participatory design [31] approaches aim to account for such individual difference, they mostly rely on verbal communication between designers and users, which clearly makes the participation of animals in the design process problematic at the basic level of mutual understanding (not to mention issues of power imbalance). Thus researchers have begun to explore non-verbal methods aiming to understand the animal's perspective. For example, Lee *et al.* [15] employed preference-testing techniques developed within animal welfare science to evaluate a haptic wearable human-poultry interface for remote tactile interaction. This was further developed by Robinson *et al.* [28], to evaluate different versions of a canine-friendly alarm interface for diabetes alert dogs, within an iterative design process in which the authors used rapid physical prototyping to elicit the dogs' preferences about different permutations of a modular design. However, these studies focused on the interaction of one animal to one prototype at a time, while in many real-life situations (e.g. farms, laboratories) researchers might deal with more complex scenarios under complex organizational constraints. *Thus how could participatory approaches be adapted to account for the needs to non-verbal individuals in complex scenarios?*

While ethnographic approaches aim to understand the complexities of real-life environments, their effectiveness is greater where access is unfettered. Indeed, multispecies ethnography has been used to investigate interactional and co-operative practices between humans and animals, and enable animals to contribute to the requirements elicitation process in studies of companion dogs with their owners [18] and working dogs with their trainers [28]. This involved socializing with and observing established human-canine partnerships in their habitual contexts, integrating ethologically informed observations of dogs with accounts from humans familiar with individual dogs and acting as mediators between dogs and researchers. Furthermore, Westerlaken and Gualemi [43] proposed a digitally complemented ethnographic approach to investigate human-animal interactions, where human-animal pairs would engage in activities such as play, while ambient biosensors would monitor and compare their physiological parameters. However, in many contexts (e.g. farms, zoos) human actors may not have enough knowledge of individual animals or the availability to act as mediators (e.g. because of work schedules or animal turnover) and engaging directly with the animals may not be viable (e.g. for health and safety); on the other hand, it cannot be assumed that biometric variations in different species would map to comparable inner states. *Thus what other ethnographic approaches might be possible in these cases and what potential might digitally enhanced ethnography have?*

THE STUDY

Fully addressing the above questions will require an extensive research program; as a first step in that direction we conducted an exploratory field study. The specific aim of this research is to support the development of ubicomp solutions to enhance the welfare of confined animals. In particular we focus on dogs in kenneled accommodation, and in this context we carried out an ethnography study to scope and elicit essential requirements for a smart environment supporting the welfare of kenneled dogs. The study took place at one of Dogs Trust's state-of-the-art dog rehoming center in Loughborough, which hosts some 150 dogs at a time.

Figure 1. Book with dogs' profiles in the reception area (top) and outdoor enclosure for exercise (bottom).

Methodology: research approach

The field work took place over a period of four months, during which we visited the center 2 to 3 times weekly for between 3 to 4 hours each time, taking video and audio records where allowed, as well as hand notes. To understand how the canine carers and kenneled dogs lived and worked together in the kennel environment, we met and worked with many canine carers, sometimes shadowing them (e.g. observing food preparation and feeding) and talking to them (e.g. to get a better understanding of daily routines), and helping with daily activities (e.g. walking dogs, cleaning kennels) where allowed. In our discussions with the carers we followed an interview guide including questions about: 1) the wellbeing and behavior of dogs, 2) carers' and dogs' daily routines and activities, 3) information recorded and methods of recording and managing it, 4) perceived potential roles and benefits of technology for dogs and carers. When appropriate, we deviated from our guide to follow emerging discussion threads. With respect to the dogs, we took care to always wear the same staff uniform for visiting the site, in order to help resident dogs familiarize with our scent. Indeed, as part of our ethnographic approach, we had expected to be able to spend a considerable amount of time with the dogs themselves, but the organisational constraints of the kennel environment meant that this was not possible.

Figure 2. Rehoming kennel seen from the visitors' side (left) and from the other side where carers' accessed it from (right).

Methodology: research challenges

In previous research involving dogs and their carers [18,28], we had been in a position to come close to these relationships, and get to know each individual dog both through their own direct observations and through the insights their guardians shared with us. Additionally, the close relationship the guardians had with their dogs gave us access to the animals in virtue of what we might call *transitive trust* (i.e. the trust the dogs had in their humans and the trust that the humans had in us meant that the dogs also trusted us, thus allowing us to come close). However, due to the inherently stressful nature of the kennel environment and the fact that the close presence of strangers could have affected the dogs' welfare and behavior, in this case the researcher was unable to come into close contact with them, although he spent time in their presence under the carers' supervision. Furthermore, due to the canine population's turn-over and unknown background typical of a rehoming kennel, carers had little familiarity with many of the dogs, thus they were unable to provide the kind of intermediation described above. Nevertheless, given the environmental constraints, the carers were our intermediaries and it is through them that we collected data via informal conversations, or through shadowing and helping with care-taking activities. While we were limited in the level of insight that we could attain on individual resident dogs, through the carers' accounts on their longitudinal experience in the kennel environment, we were able to begin to assess the effects of that particular kennel on resident dogs in more general terms rather than on specific individuals who happened to be resident at that time (for example, we learnt about highly relevant events which occurred before or after the study). Generally, because our access to different areas needed to be planned, our exchanges with staff were more formal than they might be in other ethnographic work, making it more difficult for us to 'blend in'. Also, since some carers preferred not to be audio or video-recorded, we needed to take notes in situ making our presence more conspicuous or rely on our recollections following our visits. Additionally, we were alerted to the fact that our gender could influence the dogs' response to us: since most carers were female some dogs were likely to react differently to the presence of unknown males.

Findings: the kennel system

Kennel setting. The rehoming center was one of the charity's flagship facilities with up-to-date, spacious and clean kennels. The flow of dogs through the center specifically aimed to make the dogs' stay at the center as short as possible. Upon arrival at the kennel, often with unknown background, new dogs spent a week in the Intake part of the building, where they were monitored to assess their health and behavior. Following this initial assessment period, the dogs moved to the Rehoming (Figure 2) section, where they were usually placed in pairs in an attractive enclosure, featuring a living quarter and a sleeping area, with one of its sides made of glass and overlooking the corridor accessed by visitors and potential adopters. Some dogs would only spend a few days in this kennel before being selected for rehoming. Once a dog had been reserved he was moved to the Reserved area in order to free up the Rehoming area for other dogs. A few dogs, who were considered difficult to adopt (perhaps due to health conditions or complex behavioral issues), were placed in an area with larger kennels with courtyards where they could live for longer periods. Dogs with difficult behavioral problems, following assessment, were placed in a different building, called Star, and underwent specialist training and care in an effort to 'and give them a chance to find a home once ready. Dogs who were found to be unable to cope with humans or with any training were allowed to live as a group in a Sanctuary area, where they were sheltered, fed and monitored with cameras but generally not interfered with until they were de-stressed enough to start training. Another special section, named Puppies, hosted pregnant bitches and their puppies, where special hygiene measures were in place.

An additional building, dabbed Training and Behaviour, was visited regularly by dogs on various behavioural training programs. The complex was surrounded by large grassy areas where dogs were taken on regular walks by staff and / or volunteers. It also featured outdoor training and play areas (Fig. 1 bottom) where individual or paired dogs could spend time. Additionally, there were: cutting edge veterinary facilities (including hydrotherapy) used in partnership with local academic institutions; grooming equipment (including multi-level showers for dogs of different sizes); dedicated kitchens for food preparation; and a welcoming visitor reception and lounge, featuring a large over-head screen display and glossy books presenting dogs available for rehoming (Fig 1).

Staff. The rehoming center counted approximately 40 members of staff, some of whom worked on a part-time basis. Their roles included site managers, veterinary assistants, canine carers, cleaners, staff liaising with potential adopters, and a large group of volunteers who helped in a variety of tasks, from cleaning kennels to walking dogs. Routines were run on a strict schedule to help the dogs settle in. Staff had different levels of training and expertise, being trusted to work with dogs with varying levels of complex behaviors; for example, junior carers and volunteers could walk the 'easy' dogs, while more challenging dogs needed the expertise of senior carers.

Non-digital smartness. The center was at the top-end of dog caring environments and its architectural features and working practices were clearly designed with the dogs' welfare in mind. For example, in the Rehoming section, the glass wall overlooking the corridor was specifically designed at an angle (Figure 2, left) to make potential adopters pause at each kennel, thus enabling potential adopters to pay attention to each dog individually instead of walking past the kennels hurriedly. The glass was angled also to afford the dogs a forward facing view without a direct (potentially threatening) vista of the opposite kennel. The choice of glass (instead of metal bars) for fronting the kennels on the visitors' corridor was also aimed at making the dogs feel safer. A member of staff reported: "*Unlike with bars, dogs know that strangers* [i.e. visitors] *cannot get to them through the glass, so they feel less anxiety*". Consistent with this, although the glass fronts featured doors, these were only ever used for cleaning in the absence of the dogs, so they would not learn that access through the glass wall was possible. This allowed that side of the kennel to be used as the resting area, which meant that visitors would see the dogs while these were relaxing. For another example, the corridors outside the back of the kennels (Fig 2) were divided from the grounds' walkways by partitions featuring a four-foot-high lower part in solid wood and a top part in glass; so, from his kennel, a dog could not see other dogs who might have been walked past by carers and would not be threatened by the sight of stranger dogs. The partitions also worked as an acoustic buffer with respect to neighboring properties, which meant that the dogs could be allowed into the living quarters (Figure 2, right) of their kennel at all times; this also meant that the dogs didn't need to soil their sleeping area if they needed to relieve themselves during the night. Furthermore, after being assessed, dogs were mostly placed in pairs (Figure 2, right) with suitable companions and staff took care to encourage friendships between dogs, in order to increase their psychological wellbeing. The kennels were furnished according to the requirements of resident pairs, for example with bunk beds which provided cover for the dog at the lower level, and with a range of bedding materials. Staff also used 'puzzle feeders' to make feeding more stimulating and toy rotation to provide variety, and there were numerous radios and TVs dotted around the place for additional distraction and stimulation. Additionally, dogs were sometimes relocated to new kennel to diversify and optimize their environmental exposure. In other words, the establishment had put in place many possible welfare-supporting solutions that non-digital technology and protocols could afford. Nonetheless, in spite all of the measures in places, a kennel environment still raises welfare challenges. Thus, our study aimed to explore how ubicomp technology could enable the centre to go further in supporting the welfare of the dogs and reduce the impact of confinement.

Information. Copious amounts of information about the dogs were recorded on paper in the form of books (Figure 1, top), short hand-written messages or information sheets, and kept in various locations (e.g. notes about diet and medication plans pinned to information boards in relevant work areas, printed leaflets with the dogs' description and required rehoming environment attached to the kennels' fronts or available at the reception desk). This information was regularly transferred from one part of the complex to another as required, for example following the relocation of the dogs at different stages of the rehoming process. Additionally, medical and dietary information on individual dogs was manually updated to ensure consistency in care practices. However, due to the nature of the recording medium, such information appeared to be fragmented and spread across different areas, therefore it was not always easily available to the carers. Sometimes, due to more pressing tasks, the recordings were not immediately updated (e.g. notes about dogs who had already been rehomed might still be hanging on the walls). Occasionally, information loss could occur (e.g. during a dog's relocation) and as a consequence staff might be unable to identify different dogs or their specific requirements. Due to spatial constraints, some information was located in areas which were not used by all staff, thus carers might end up not benefitting from it, unless they were specifically required to focus on one individual dog.

Findings: challenges and opportunities

We learnt how, due to the logistical challenges faced by rehoming environments, resident dogs spend significant amounts of time in their kennels, with limited access to external stimulation other than watching staff and visitors, being walked and fed. In spite of the efforts made to alleviate isolation and boredom, confinement seemed to affect some of the dogs, who displayed a range of behaviors. These could include potentially problematic interactions with others (e.g. reacting to other dogs and to staff by barking loudly or biting, lunging towards the kennel's front glass, guarding of food or toys by growling on approach); for example, one Labrador-Staffordshire female cross in Rehoming appeared very reactive, barking insistently at visitors, while staring at them and stamping her front paws against the ground or glass front. Other behaviors might include active self-stimulation (e.g. spinning, pacing, self-biting, ripping bedding); for example, we observed one mix-breed male seemingly mating with his own bedding for extended periods of time. Passivity (e.g. withdrawal) might also occur and we observed an Afghan hound male, who had been adopted with his canine buddy and subsequently returned alone, spending most of his time inactive on his bedding. During the informal discussions with carers and volunteers, as well as during a discussion session following a seminar and focus group organized for all the staff at the centre, a number of themes emerged in terms of what were considered to be desirable properties that could form part of the smart kennel set-up, but also the complexities associated with each of these desirables. The following dimensions emerged from pour findings:

Stimulation. Carers felt that additional stimulation, such as activities in the kennels or training challenges during walks, could enrich the dogs' daily experience and hence enhance their welfare: *"...in the kennel something interactive…if they are singles it could be food orientated but if a group it would be more game orientated…could be as simple as a button they press and food comes out…even a TV I suppose, something for them to watch or listen to..."; "…things for them to investigate along the way* [on a walk]*… "*. However, carers were also conscious that introducing new items of interest in double occupancy kennels might trigger competitive behavior to the detriment of the weaker individual: *"...a food dispenser could cause jealousy if another dog in the kennel is not being fed...there is some severe food aggression with the dogs, even if you have one piece of biscuit they will have a go at you..."*. Also, carer pointed out that "…*different dogs might react differently to the same stimuli*...", with certain sounds, for example, being aversive to a dog while positively stimulating for another. Carers felt that, while good for some dogs, stimulation could also possibly lead to over-excitement and induce behaviors such as excessive barking, resulting in a significant increase in noise levels to the detriment of the more sensitive dogs' welfare; thus any form of digital enrichment would need to embed mechanisms to dynamically manage these divergences.

Control. Carers wished they could afford the dogs more freedom of movement beyond their living quarters, for example during the night, but managing unrestricted movement, in such a way that it would not lead to undesirable behaviors, for example aggression between dogs coming into contact, was seen as a difficult challenge. Alternatively, carers sought to provide the dogs with ways of modifying aspects of their surroundings, for example by controlling the ambient temperature: *"...a temperature* [controller] *in the whelping room or something that could alter the temperature when you are not there…"*; or by controlling their level of exposure: *"…when dogs move up to Rehoming and Booked the front of their kennels is glass…they are not used to it…when they see their reflection on the glass and the other dogs in front of them, most of them tend not to like it...in Booked they have curtains but we can't use them up here as they don't look nice for the public..."*. However, exposure to the public and other dogs was an essential part of the rehoming process, so affording the dogs the benefit of more privacy would require the implementation of careful trade-offs.

Assessment. Carers wished for ways of monitoring the dogs, either to aid assessment of their personality and welfare at Intake or for ensuring their continuous wellbeing. Since the act of physically monitoring the dogs, particularly at night, could easily create a disturbance, the possibility of continuous monitoring was deemed potentially very valuable to identify behavioral patterns which might have emerged. For example, Training and Behaviour staff noted: *"…we have always known that sleep patterns are highly indicative of welfare but have limited means to monitor, this would be extremely useful…"*. Equally, it was considered that being able to monitor for signs of acute illness would facilitate early intervention with appropriate medical care. It also emerged that providing indexed records of the dogs' behavior and social interactions (e.g. in the event of a fight) could enable carers to quickly access salient events (e.g. the breaking of the fight), particularly for the Sanctuary area: *"…we already have cameras in Sanctuary that really show the usefulness of it…the down side to it…typically everything will happen outside the range of the camera…it also means you have to relook at everything…"*. Being able to know about welfare salient events in real-time was also deemed potentially important: "…*some form of being able to monitor what is going on such as frustration and heart rate to find out how stressed they are getting and potentially what caused that…"; "…it needs something that is going to instantly flash up that a dog is spinning or is pacing...or there is a peak that could suggest there is tension..."*. However, carers were already manually recording and managing a wealth of information, which appeared to constitute a significant overhead, thus any monitoring solution would need to ensure that an increase of digitally produced information would not add to the load.

Information. Carers wished to be supported in managing information, both what might be recorded automatically (e.g. physiological data) and what they were already recording manually and sometimes informally (e.g. notes on routine activities). They noted that a more centralized system allowing all carers to access detailed records on any dogs or be alerted to any issues requiring intervention, could enable them to work with greater flexibility: *"…when dogs transfer from Intake to Booked, the staff on those blocks don't know the dogs…you have to transfer things to the walking board, and the food board and then write stuff up sheets for outside the kennel and there is never enough space…it would be good to have something like an interactive whiteboard where it just pops up and then another in the kitchen with this information…"; "…you could have movement of dogs recorded so when a dog comes in they have their own page and when they move from one block to another...so having it done electronically would be a lot easier because you wouldn't lose dogs ever…"; "…you could look back over the past few days for example if someone has been to the vets and you don't know their stitches could fall out…".* Carers also wished for some technological solution to help them match dogs to the right adopters: "*…being able to match dogs to people more easily…we obviously have criteria for all the dogs when people fill in the thing, but a lot of it comes down to Rehoming looking at the form and thinking which dog do we have…some dogs are a bit out of sight and it is remembering they exist and checking…".* In this respect enabling carers to easily record mundane details and observations about each dog (e.g. what happens during a walk) could contribute to building a richer profile of the animals and making them easier to match.

DISCUSSION

Multi-pronged smartness

Rehoming kennels are complex, dynamic multispecies systems, characterized by contrasting requirements. Dogs are sheltered with the intent of improving their lives through rehoming, yet the confinement implied by the rehoming process can negatively affect their welfare: solutions adopted to combat boredom can cause over excitement, frustration or social tensions. Combined with confinement, exposure to the public may affect some dogs, yet it is through such exposure that they get the chance to be rehomed. Efficient operation of the system relies on a level of standardization, yet resident dogs are individuals and interventions benefiting one dog might be unwelcome to their kennel companion. Knowing individual dogs is key to managing their physiological, psychological and social needs, but most dogs have no known history when they arrive. Ubiquitous monitoring of individual dogs might help, but any monitoring system would have to contend with multiple dogs at once. While interaction designers are familiar with needing to negotiate and reconcile requirements divergences, the very functioning of the kennel environment seems to depend on the careful balancing of contrasts, posing specific design challenges which any technological intervention has to address. Thus ubicomp interventions will need to provide concurrent and coordinated support on different fronts. Specifically, based on our findings, our research draws attention to the following dimensions:

Ambient interactivity. We have seen how having control over one's environment, being able to predict what might happen next and having access to an appropriate level of stimulation are important aspects of good welfare. Therefore providing kenneled dogs with a responsive environment and a variety of stimulating interactions is a potentially important area of ubicomp application. For example, this could be in the form of interactive entertainment (e.g. toys) or architectural features (e.g. partitions), which enable the dogs to change their surroundings through interaction with dog-friendly interfaces, or which automatically adapt to the dogs' behavior, thus giving them more of what they want or what can best support their health and wellbeing in the long run. Affording them environmental control is also a way of increasing understanding of what may improve their welfare as expressed by their preferences.

Pervasive monitoring. On the other hand, in order to best support the dogs' wellbeing and give them what they want their environment needs to gather information about them individually, their normal behavior and any deviations, and their responses to any recorded environmental changes. As discussed, some welfare parameters are difficult to measure unobtrusively and their meaning is difficult to interpret, particularly in terms of inner states, and particularly when measured in isolation and in the short term. Therefore any monitoring of welfare indicators could be multimodal, continuous and long term; such monitoring could focus on parameters which can easily be monitored without impacting on the dogs (e.g. acceleration) and which are relatively easy to analyze automatically (e.g. activity), thus supporting the carers in their interpretation and in the identification of emerging patterns.

Information management. While automatic data analysis could be very useful for identifying welfare-salient patterns, ultimately the interpretation of those patterns and how the environment should respond rests with the carers. For example, they might need to decide whether continuing to give a dog what he wants in the short term is detrimental to his health and wellbeing in the longer term, and thus whether his will needs to be temporarily overridden. To be able to make the best possible decisions, the carers would need to have efficient access to contextually salient information (e.g. canine activity data above given thresholds respective to activity location). To maximize context relevance during day-to-day working practices, a centralized system could enable carers to easily access and input relevant information while mobile (e.g. via their phone), automatically updating the dogs' records as they move through the kennel system.

Our research suggests that integrating *ambient interactivity*, *pervasive monitoring* and *information management* is necessary in order to enable smart environments to address the divergent welfare needs of different individual animals, within a multispecies setting whose efficient functioning requires the smooth flow and use of disparate information, and the timely fulfilment of hectic routines. The following scenario illustrates our vision for such an environment.

Rehoming Freddy

A small Staffordshire Terrier cross has just arrived at the center. He was picked up from a street in a neighboring county and nothing is known of his background. He appears to be very timid, tale between his legs and head down most of the time. Using her tablet at Intake's reception, a carer creates an electronic record in the center's information system, naming the little dog Freddy. She then takes Freddy to the vet for a check-up. At the end of the examination, using the clinic's desktop computer, the vet inputs new data to Freddy's record about his health, adding information such as dietary recommendations and therapeutic prescriptions: for now Freddy can eat a standard diet, but he has an eye infection and will need medication at regular intervals twice a day, with another visit after a week; the prescription and follow up appointment are automatically turned into diary entries for whoever will look after him each day. The vet also fits Freddy with a special collar which is wirelessly networked with the center's information system and which uses three different technologies to keep track of his activities: GPS to track his position during walks, IPS to monitor his movements within his kennel [9], a tri-axial accelerometer to monitor how active he is and what activities he engages in (e.g. walk, play, sleep), each of which will have a signature identified by a learning algorithm [25]; the collar also uses radio frequencies to monitor his heart and respiration rates [39], which the system reads in relation to activity patterns. Freddy is then taken back to Intake to the kennel which has been prepared for him; when he enters his new space, his collar transmits that to the central system and Freddy's electronic record is loaded onto a small electronic board at the front of his kennel, where his medication times are highlighted. The kennel is furnished with a bed, a platform above the bed, and two bowls, under which pressure sensors are fitted and networked to the center's information system, so the kennel will know and log when Freddy spends time in bed, on the platform, eating or drinking. There are also two toys containing IPS and a tri-axial accelerometer, to allow the carers to see when and with how much vigor Freddy plays with them. At first the carers notice that Freddy spends all his time hidden in his bed during the day, pacing up and down the kennel during the night, hardly ever visiting his bowls, and never even touching his toys, so they put him on a special training program to help him gain confidence. Over a number of days the pattern changes and Freddy seems to become more active during the day, spending time on top of the platform or manipulating the toys. However, he still rarely moves towards the front of the kennel and the system highlights that this only happens when Lucy, another small Staffy, is walked past. Having compared the electronic records of the dogs, the carers stage an encounter between the two in one of the outside areas, recording the outcome and pairing the dogs up in the system, via their mobile app, before transferring both to a shared kennel in Rehoming.

When Freddy and Lucy arrive at the rehoming kennel, their records are automatically transferred: rehoming requirements are displayed on an electronic board in reception and next to the glass wall through which visitors look at the dogs; caretaking routine schedules are displayed at the other end of the kennel where carers access the dogs. The kennel features the same furniture as in Intake, except on one of the walls there are two devices: one is a soft rubber sausage, similar to the toys they had in Intake, except this is attached to a cord; the other one is a screen with one large grey touch pad underneath, one slightly smaller blue touchpad on one side and one yellow touchpad of the same size on the other side [20]. The sausage is the interface for a toy distributor, which capitalizes on the fact that dogs like to tug objects to make it easier for the resident dog to opportunistically discover its function; indeed, soon Freddy learns that if he pulls the sausage a randomly selected toy drops from a flap in the wall. The screen and pads are an interactive canine television, which can be activated by nose-touching the large grey pad; consistent with canine psychology, the smaller pads are feedback input devices, with the yellow indicating 'like' while the blue indicating 'dislike'; doing nothing allows a 'program' to just continue, touching the 'like' pad change the program to something similar, while the 'dislike' pad changes it to something completely different. The television stops working automatically after five minutes of non-interaction. Freddy really doesn't get this one, whereas Lucy learns to start the first program, which she does quite often, while timid Freddy ends up at the opposite end of the kennel; the carers think Freddy doesn't like the television and, to give him a break, set it to become inactive for an hour after fifteen minutes of use. The other device in the kennel is a panel curtain, which can be drawn in front of the glass to screen it, thus visually isolating the dogs from visitors. Freddy is no fan of strangers and quickly learns that 'nosing' the edge of the panel, where a pressure sensor is wired to a small engine, causes it to draw closed; but, after ten minutes the screen opens up again so if Freddy wants to keep it close he has to keep nosing the edge [35], which he is allowed to do indefinitely most of the time. However, the carers are keen for Freddy to find a home and a couple has just showed up in reception, who live in a quiet area in a house with a walled garden, no children and no other animals, and who are prepared to adopt two dogs no matter what the breed: Staffies are not too popular and this is too good an opportunity of finding Freddy and Lucy a home together in a setting that suits timid Freddy, so the receptionist disables their kennel's screen to make sure that they do not miss out *on their chance. Indeed the couple falls for Freddy and Lucy at first sight and immediately reserves them.*

Smart ethnography

The above scenario raises a wide range of questions: What kind of inferences could be made from the granularity of data recorded by current IPS technologies? How could inferential power be maximized? Given the number of dogs living in a kennel environment, could a real-time monitoring and alerting system overload, rather than support, the carers? Could it end up taking their focus away from the dogs and onto a digital representation of them [33] with possibly negative effects? How could this be avoided? Would all the dogs be able to engage with the same interactional mechanisms to take control over their environment? Would any disruption or deactivation of interactional features confuse and frustrate the dogs? Could interactional common denominators be identified and used as design templates for further customization with different dogs? How would the introduction of novel interactive features influence the social dynamics of dogs housed in the same kennel? Investigating such questions from the perspective of the actors involved, i.e. prospective users of any technological intervention, is necessary to make specific design decisions informing the development of prototypes for testing.

However, as we have seen, the ethnographic and design approaches proposed by previous studies to address questions such as those above presupposed conditions which our research environment did not meet: time and space to be amongst human-animal social nuclei, directly engaging in prolonged interaction with both species perhaps via probes or prototypes, in settings where the animals are well-adjusted to their daily environment, and where human guardians have intimate knowledge of individual animals. Quite differently, we were dealing with a large, complex, dynamic multispecies system involving many actors, roles and routines needing to function like clockwork for the ultimate benefit of resident animals; a system in which time and space were limited, as were the possibility of coming into contact with the animals and the ability of their human guardians to act as mediators. Of course, such conditions require that the design processes aiming to produce ubicomp interventions for such settings adapt accordingly.

Ubicomp interaction designers are well familiar with the cyclicity of the user-centered design process and with how each phase blends in and overlaps with the other. But in complex multispecies environments where the effects of any technological intervention on working practices may be unpredictable, and where most of the prospective users do not speak human language while still having specific individual requirements that need to be met, the usual design cycle may start to look very different. For example, understanding what variations of which variables of an interface an individual dog might prefer may require a lot of tweaking and adjusting of each variable at any one time requiring the whole process to become a lot more agile. We propose that fulfilling the need for greater agility in the design process, within a context where researchers have limited access to their non-human users, requires, on the one hand, the adoption of rapid prototyping approaches which enable researchers to make changes without disruption and, on the other hand, ways of quickly identifying correlations between those changes and the response from canine (and human) users. In this respect, ubicomp has a role to play, not only as a part of the solution to the problem of animal welfare, but also as a research tool to enhance the design process, where simple forms of rapid prototyping and monitoring could be integrated to elicit detailed design requirements. Of course, this raises issues which researchers will need to explore, such as the extent to which ubicomp can be relied upon as a research instrument or the extent to which ubicomp research practices might impact on participants' privacy, where the experimentation of such research practices can help shed light.

It could be argued that animals who live confined have little saying over their own lives, so regarding them as *users* is ironic. However, only by regarding animals as legitimate users of the environments they inhabit, can one begin to design interventions that support their welfare by fostering their health and giving them more of what they want. By developing design approaches and solutions that enable animals to express themselves, researchers can give them a voice; by supporting those responsible for them, researchers can enable those to better hear that voice.

CONCLUSIONS

Our ethnographic study of a rehoming center for dogs has highlighted a number of dimensions that are central to the design of a smart kennel for supporting canine welfare. We propose that ambient interactivity, pervasive monitoring and information management are three such intertwined dimensions aiding the management of diverging requirements which need to be carefully balanced. We see these as fundamental to an overarching design framework to support the process of designing and developing concrete features of future smart kennels, as our scenario illustrates. We also propose the agile combination of rapid prototyping and monitoring as a ubicomp research tool to inform the design process as required by the particular settings. Ubicomp researchers have shown their creativity in overcoming many of the obstacles inherent in bringing new visions of ubiquitous computing into practice; it is now time they do so for complex environments that involve animal stakeholders. These environments can no longer be considered as niche areas of interest, but represent a societal challenge that needs to be addressed.

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