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Posture Estimation for a Canine Machine Interface based Training System

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Abstract— **Dogs and humans have worked in partnership throughout history thanks to dogs' unique capability of detecting signals in human voices or gestures and learning from human inputs. Traditional canine training methods rely solely on subjective visual observations made by trainers. We propose a canine body-area-network (cBAN) to incorporate context-aware sensing with objective detection algorithms to augment the sensitivity and specificity of human trainer's awareness of the dogs they are training. As an initial effort, we developed a Bluetooth-based wireless infrastructure and tested inertial measurement units as cBAN sensor nodes to electronically assess the posture of the dogs. As a result, we were able to optimize the sensor locations and distinguish different postures using the distinct patterns in the measured angles.**

I. INTRODUCTION

In this paper we present our initial efforts to develop the technology that will enable ***canine computer interaction.***

The human-canine partnership can be traced back to 30,000 BC [1]. Throughout history, these animals were domesticated and trained to help us with daily tasks such as hunting, herding, protection, and companionship. Even today, our urban lives are enriched with the service of working dogs for detecting chemicals, guiding the blind, acting as psychological therapy dogs, etc.

Dogs are highly social animals which communicate with each other through vocal, visual, olfactory and tactile signals [2,3]. Living closely with humans for thousands of years, dogs have become very effective at detecting changes in human voices, facial expressions and body language. Similarly, during the training or handling of dogs, astute trainers learn to detect distinct signals from dogs based on their vocalizations, body postures, and behaviors. When these are effectively interpreted, trainers can be far more effective at teaching their dogs new tasks and pet owners can better manage their dogs' interactions with people, other dogs, and the environment. However, learning to interpret canine signals, in order to assess emotional states or predict future behavior, may be a challenge for non-professionals such as pet-owners training their dogs at home or disabled people working with professionally trained guide-dogs. Misinterpretation of canine signals may lead to confusion.

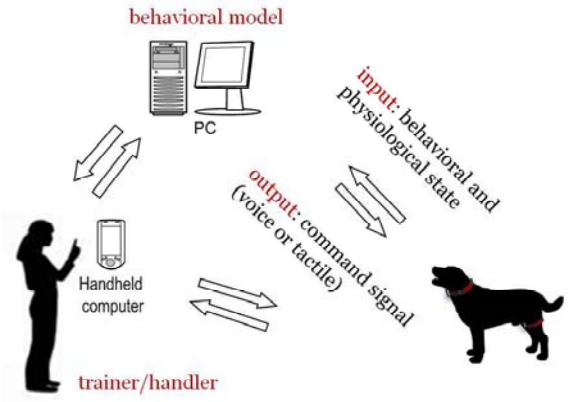

Figure 1: Canine-machine-interface-based closed-loop dog training system

Unfortunately, the inherent subjectivity of interpreting dog's behaviors and poor training methods, combined together, may induce problematic behaviors among dogs which may lead the cessation of a working human-canine partnership [4,5]. In order to reduce ambiguity in communication signals between dogs and humans, we propose a novel technological communication aid involving the use of computers to form a closed feedback loop between human trainers/handlers and dogs (Figure 1). This is achieved by a canine body-area-network (cBAN) formed by an electronic sensor-actuator infrastructure worn by the dog. The cBAN comes with bi-directional wireless communication capability to a hand-held device operated by the human and to a remote computer simultaneously. The human-canine interaction is registered by the computer through dog-worn sensors and human-operated handheld device and the relevant physio-behavioral information (the signal) is fed to a computational model of dog behavior. The model uses the same communication channel to provide feedback to the canine through the worn actuators that generates positive reinforcement for behaviors the dog has learned. Once completed, this ***canine machine interface*** will enable a novel paradigm in training and handling not previously possible that will make training dogs more accessible to non-experts and physically disabled dog owners.

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In this study, we present the use of inertial measurement units (IMU) as sensor nodes of our cBAN and testing of various sensor locations. Developing wearable technologies for canines comes with different challenges. Most notably, few dogs will tolerate cumbersome electronic packages strapped to their bodies. Therefore, there are a limited number of sensor sites available to pick from. Different postures may result in similar data depending on how the IMU is aligned with respect to the dog's body and gravity, thereby requiring a multi-sensor measurement to assess the posture of the dog accurately. The localization of these IMU is a critical design criterion for measurement accuracy, and furthermore, for power reduction where the power should be budgeted for long term operation with available batteries. In the remainder of this paper, we describe our initial efforts to use inertial measurement units to detect a range of postures. Our approach is to use three-axis accelerometers in concert with gyroscopes to help account for any drift in the measurements. In particular we focus on sensor site selection for reliable posture classification.

II. BACKGROUND

Animal-machine interfaces have been proposed in the literature for several purposes, from understanding brain activity during the two-way interaction between primate brains and prosthetic arms [6-8], to navigating the locomotory behaviors of insects by neuromuscular stimulation [9-11]. Instrumented backpacks/collars were also developed especially for police dogs that contain GPS-based tracking systems [12], eye-view cameras [13] and stimulation systems providing vibration, digital voice or electrical shock [14]. Jackets with biopotential electrodes, thermocouples and strain sensors have also been used to collect heart rate, skin temperature and respiratory rate information in veterinary laboratories [15]. However, these systems have been used only in an open-loop and unidirectional fashion either to collect environmental/physiological information or to provide negative reinforcement training input to the animal to avoid certain behaviors. The canine machine interface based closed loop system proposed here (Figure 1) will combine behavioral and physiological information with positive reinforcement to allow computers to assist humans in training and handling dogs. In a separate research effort we are developing novel machine learning algorithms that will leverage these actuators to provide the reinforcement, thereby aiding or even replacing humans training dogs at some point in the future.

Accelerometers, gyroscopes and magnetometers have been extensively used to monitor activity level in experimental animals in laboratory conditions [16-19]. These inertial measurement units have also been used to track the motion and predict the upper limb positions in real-time on human subjects for neuro-rehabilitation applications [20]. The estimation of canine posture is a relatively new application area for inertial measurement sensors, where multiple sensors at different locations are crucial for the precise assessment of posture and motion in real-time. There has been one attempt to use multiple accelerometers to predict the posture of dogs [21]. However, the sensor sites they selected caused similar data on both sensors, and therefore limited the advantage of using a secondary sensor for increased specificity.

III. MATERIALS AND METHODS

A. Canine Body-Area-Network (cBAN)

A low-power and low-cost bidirectional wireless infrastructure is required to incorporate context-aware and objective sensing and detection algorithms for more sensitive and specific awareness of canine's behavioral responses to training (Figure 2). Newly emerging system-on-chip (SoC) solutions are promising where analog, digital and mixed-signal circuits are combined with radio-frequency functions on a single substrate level. For this study, we used a single chip solution from Texas Instruments (TI) [22]. CC2540 from TI combines an 8051 microcontroller with a high performance radio-frequency transceiver, while providing 8 KB of RAM and up to 256 KB of flash memory. It also provides tailored software to fit in with 2.4 GHz Bluetooth standards to establish connections with computers and smartphones. Optimizing the power budget is also possible with its flexible power modes. This single-chip system is an ideal solution for our canine machine interface with its 21 general-purpose input/output pins and 8 channel 12-bit analog to digital converter. CC2540 comes in a 6x6 mm^2 package.

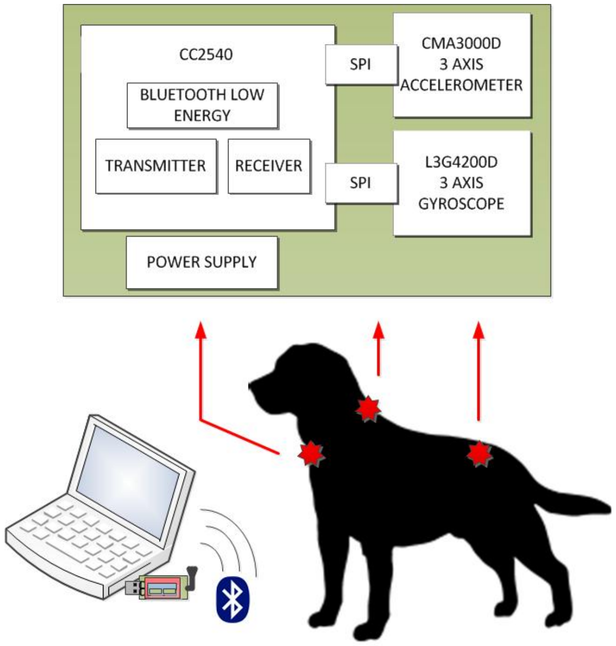

Figure 2: The block diagram of the wireless sensor system. The star signs (*) on the dog indicate the three sensor locations tested in this study.

Two different inertial measurement systems were connected to CC2540 through a serial-peripheral-interface (SPI) to set-up a sensor node. A MEMS-based three-axis ultra-low power accelerometer from VTI (CMA3000) [23] was selected as the first unit, where the system was set-up for ±2g measurement range and came in a 2x2 mm^2 package. As the gyroscope, a MEMS-based three-axis ultra-stable device from ST Microelectronics (L3G4200D) [24] was used with a package size of 4x4 mm^2. For this study, we utilized a commercial-off-the-shelf (COTS) evaluation board to connect CC2540 with the inertial measurement units and we are in the process of combining all the electronics on a single miniaturized printed circuit board. Two different sensor packages/boxes were prepared with two evaluation boards each containing an accelerometer and a gyroscope.

The sensor nodes of our cBAN will eventually be distributed throughout a COTS harness to achieve a wearable system. For this, we used the Web Master harnesses from Ruffwear, Inc. [25] with three different sizes (extra small, small, medium). Three different locations were tested for the two inertial sensor boxes: one at the chest of the animal and two at the back; one close to the head (around withers) and the other close of the tail (around rump) of the animal (Figure 2). The z axis of the accelerometer for the former location and y axis for the two later locations were physically aligned with the spinal cord direction of the dog as much as possible. The sensor boxes were attached to the harness with Velcro in two of three different locations during each of our data collection trials.

Data collection software was prepared using MATLAB to collect and store six sets of data (three-axis accelerometer and gyroscope) simultaneously received from each of the two different CC2540 units (sensor boxes) through the established Bluetooth link via a USB connected dongle (Figure 2).

B. Experimental Protocol

To test different sensor locations and animal sizes, three canines of different breeds (Shiba Inu, Kai Ken and Labrador Retriever) were used in their home environment (Figure 3). All the dogs were trained house pets and two of them were also trained hunting companions. The owners of the animals asked the dogs to perform a battery of trained behaviors (sitting, lying down, walking, and standing on two legs) repeatedly. To have a reliable correlation, the same posture was performed at least five times with the same animal. The inertial information was logged on the computer and the session was video-recorded. Both video and inertial data were analyzed off-line. All animal procedures were consistent with NIH and USDA guidelines and were approved by North Carolina State University the Institutional Animal Care and Use Committee (IACUC).

IV. RESULTS AND DISCUSSIONS

The recorded videos were analyzed manually where visual markers were used for time synchronization between video frames and the inertial data. The distinct acts performed by the animal were time-stamped. The inertial measurement data were post-processed by low pass filtering and thresholding in correlation with these timestamps. The angle of change along three axes of accelerometer data was plotted for the three tested locations: chest, back near the head and back near the tail (Figure 2). All the angle data was correlated with the postures and was relative to the baseline standing posture.

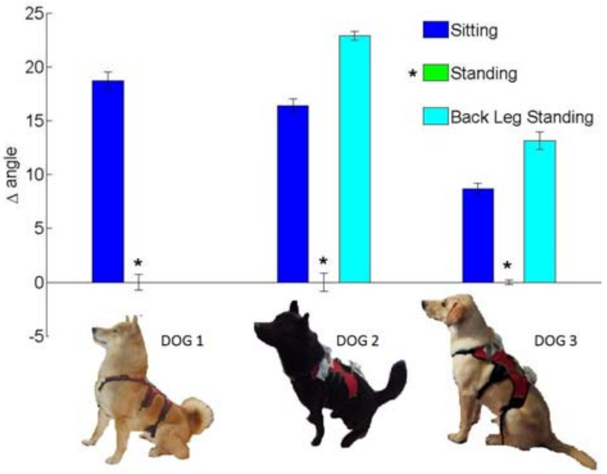

Figure 3: Three different canine breeds were tested for two or three postures. Dog 1 is missing the "Back Leg Standing" posture. The data shows the y axis data obtained from the back sensors. Error bars represent the standard deviation of the mean.

Consistent positioning of the accelerometers between trials and animals helps maintain a similar amount of angle change for similar tasks with different dogs. The gyroscope data can be used to correct the misalignments in the accelerometer positioning. However, even if the positioning is not very accurate and the multi-sensor correction is not applied, the patterns in the angle change still can be used to distinguish and estimate the separate postures to a certain extent. Figure 3 compares the angle change obtained in all three dogs for four postures (sitting, standing, walking and back leg standing) as collected by the sensors on the back. We observed repeatable distinct patterns in the y axis for all four posture types in all the dogs. During standing, the horizontal position of the sensors was not altered where the average angle change was not significant. Sitting posture caused a change in the order of 5-10 degrees while two-leg-standing changed the y axis angle more than 25 degrees. Both the front (near the head) and rear (near the tail) sensors had very similar patterns (Figure 4).

The back of the dog was horizontal during both standing and walking postures, therefore a single system at the back (either towards the head or back) was not reliable by itself. To distinguish these two postures accurately, a second sensor at the chest was used where a larger change was observed during the walking behavior (Figure 5).

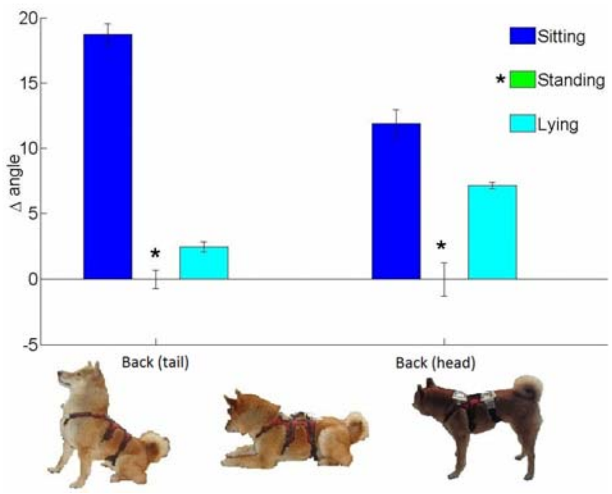

Figure 4: Comparison of two back sensors (one near the head, other near the tail) for three different postures performed by Dog 1. Error bars represent the standard deviation of the mean.

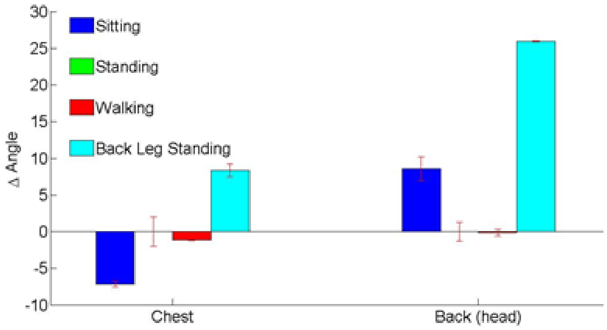

Figure 5: Comparison of chest and back sensors for four different postures of Dog 1. Error bars represent the standard deviation of the mean.

V. CONCLUSION

In conclusion, we were able to observe distinct patterns in the angles measured by inertial measurement units during different postures. The two sensor boxes located at the back (one near the head and one near the tail) demonstrated similar patterns; whereas the third sensor box on the chest demonstrated distinct but dissimilar patterns with these two. These initial measurements are a very promising indicator that inertial measurement units are sufficient to accurately assess posture of the dogs. The assessment of posture is a crucial first step toward electronically detecting behaviors of the dogs for the canine-computer-interface-based closed-loop dog training system we are developing. This system has great potential to augment our partnership with dogs.

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