

Wearable Wireless Biophotonic and Biopotential Sensors for Canine Health Monitoring

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Abstract—There is an increasing interest from dog handlers and veterinarians in the ability to continuously monitor dogs' vital signs (heart rate, heart rate variability and respiration rate) with the aim of identifying physiological correlations to stress and excitement outside laboratory environments. We present our latest efforts towards a novel non-invasive wearable sensor system including photoplethysmogram (PPG) and electrocardiogram (ECG) to remotely and continuously monitor vital signs of animals. To overcome the limitations imposed by the dense hair layer, we investigated the use of pointed style electrodes, traditionally used in training (shock) collars, as passive ECG recording electrodes. We also studied the incorporation of light guides and optical fibers for efficient optical coupling to the skin. The ECG and PPG sensors were interfaced to a system on chip (SoC) with Bluetooth capability for transferring the data to a nearby smartphone or computer for data storage and analysis.

Keywords—computer applications; inertial measurement unit; animal machine interface; physiology; cascade learning;

I. MOTIVATION

Accurate interpretation of canine behavior is essential in human-canine interactions to achieve effective training and for dog welfare. Traditionally, handlers look for gestures, vocalizations and behavioral signs of anxiety (shaking, restlessness, visual scanning and yawning) to determine the canine emotional response to a certain stimulus or condition. There is an increasing interest in making this process less subjective by continuously monitoring working, service and pet dogs' vital signs as indicators of emotional status and welfare and to identify triggers of stress and excitement outside of laboratory environments. This could then be used to define more comfortable environments and conditions where training and interaction with dogs could be done more efficiently. Postural recognition and canine body language are valuable indicators of stress or excitement, but more accurate interpretation of emotional response can be obtained by correlating these behaviors with heart rate, heart rate variability and respiration rate [1-3].

With the goal of enhancing human-canine interactions, we have developed a canine-body area network (cBAN) that combines wearable sensing technologies and computational modeling to provide handlers and trainers with an accurate estimation of dog behaviors and emotional state [4-6] (Fig. 1). The cBAN worn by dogs consists of sensors to monitor their

physiology (ECG and PPG) and inertial measurement units (IMUs) (accelerometers and gyroscopes) to monitor their behavior. The sensor data is transmitted wirelessly to a computational node where the data is interpreted and information about the dog's behavior and physiological state is presented to the handler.

The capability of detecting static dog postures (sitting, lying down, standing, eating off ground and standing on two legs) and dynamic activities (walking down a ramp, climbing up stairs and walking) has been shown in our previous efforts [4,5]. High classification accuracy of these behaviors was achieved by using a cascade of machine learning classifiers consisting of Hidden Markov Models and decision tree classifiers. In this paper we will focus on the design characterization and performance of the biophotonic and biopotential sensor system to gather physiological data (heart rate, heart rate variability and respiration rate) of canines in real time.

The use of IMUs combined with GPS has been used for localization and estimation of animal behavior and activity levels in companion animals and livestock [7,8]. These attempts are limited in the set of behaviors that can be detected and none of them offer simultaneous monitoring of vital signs.

The ability to effectively capture the emotional responses and welfare of dogs may yield measurable benefits during the training process where handlers can more accurately identify comfortable environments and reduce the exposure to stress inducers [9].

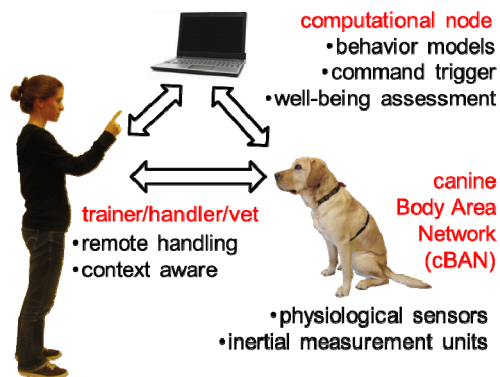


Fig. 1. General description of the canine-machine interface to enhance human-canine interactions.

II. BIOPHOTONIC AND BIOPOTENTIAL SYSTEM DESCRIPTION

A. ECG

The traditional ECG method used in the clinical setting requires shaving of the animal body parts to attach ECG electrodes where the surface electrodes are prone to detachment due to the movement of the animal [10]. Securing of these has been achieved with tape and bandage which is time-consuming for daily use and may be uncomfortable for animals [11]. Most of these clinical systems provide only on-board recording capability, and the wireless systems are expensive for home-use [12]. Implantable sensors are also expensive and require intense surgeries [13].

The proposed non-invasive wearable monitoring system has the PPG and ECG sensors mounted on a chest strap (Fig. 2). Stainless steel pointed style electrodes, traditionally used in training (shock) collars, have been used as passive ECG recording electrodes. The pointed shape of these electrodes overcomes the limitations imposed by the dog fur.

B. PPG

PPG is a volumetric optical measurement that is obtained by shining infrared light into tissue and detecting the amount of light that is reflected to the photodiode. The traditional PPG recording has only been used on anesthetized animals during surgeries where traditional pulse oximetry clips were attached either to the ear or tongue of the animal, thus not available for home-use [14].

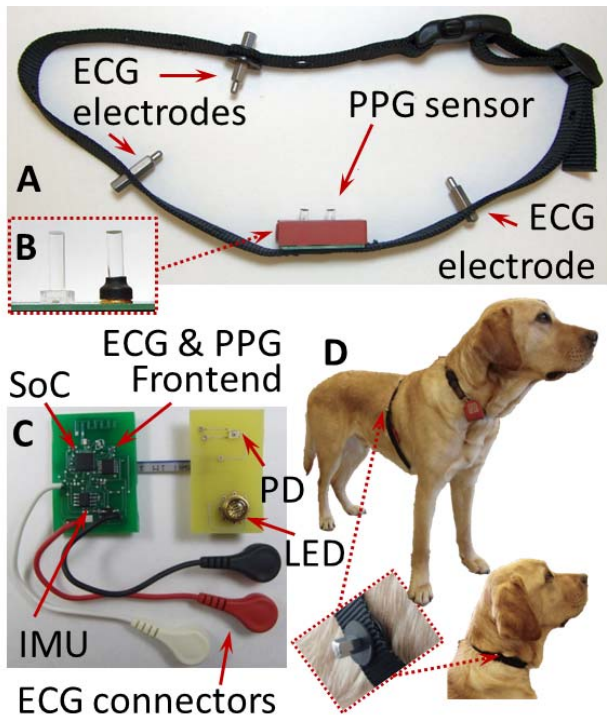


Fig. 2. (A) Chest strap including ECG and PPG sensors (B) Shows the light guides for PPG recording (C) Printed circuit boards for ECG and PPG measurements and Bluetooth wireless transmission (D) Labrador retriever with the sensor on the chest and the neck as alternative location.

In PPG measurements, canine fur becomes a barrier because most of the light is reflected by the hair, causing very little light to penetrate the tissue. We studied the incorporation of light guides that utilize internal reflection to homogenize non-uniform light sources and optical fibers for efficient optical coupling to the skin. In our system a multiwavelength LED (Marubeni) working at 850 nm is used to shine light into the tissue, and a single package commercial-off-the-shelf (COTS) component containing a photodetector and transimpedance amplifier (TSL12T) is used to detect the modulated light exiting the tissue (Fig. 3).

A silicone structure is used to hold the light pipes at a fixed distance and orientation respective to each other, benefiting the pipe-to-tissue coupling. Silicone also acts as an optical barrier to prevent direct light from the LED to reach the photodetector directly.

In order to reduce $1/f$ noise, the LED is pulsed at a rate of 500 Hz; these pulses are generated by the Texas Instruments (TI) CC2541 microcontroller while the current is sourced by an op amp. Photon populations received by the photodiode retain the frequency of 500 Hz and a sample and hold circuit is required to demodulate the arterial pulsation signal. Once the DC bias has been removed, the signal is amplified, filtered off high frequency noise and sent to the microcontroller's ADC on an introduced bias. The CC2541 provides Bluetooth capability for transferring the data to a nearby smartphone or computer for data storage and analysis (Fig. 4).

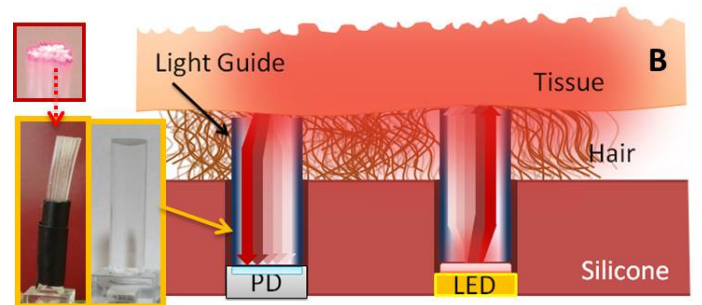


Fig. 3. Operation of PPG sensor Light guides in the photodetector and LED for tissue coupling. On the lower left, a close look of the light pipe and also optic fiber bundle for further enhancement. Silicone is used for structural support and to block direct light transmission from LED to photodetector.

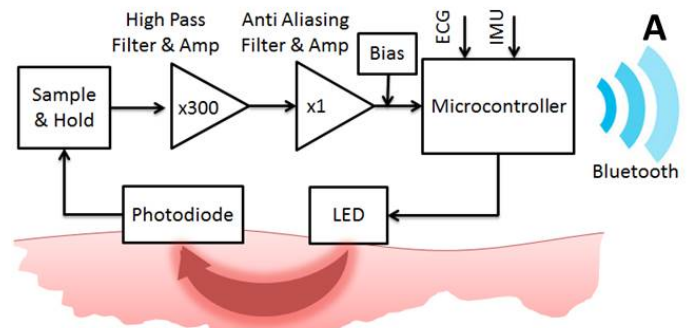


Fig. 4. System operation of PPG sensor

III. SYSTEM PERFORMANCE

Testing of the novel non-invasive wireless monitoring system was performed on two dogs, a 3-year-old Labrador retriever and an 11-year-old mixed breed. Fig 5 shows PPG signals that demonstrate the heart beat and respiration related modulations. The respiratory modulation shows a respiratory rate of 6 breaths-per-minute that was obtained from the Labrador retriever in deep sleep. The ECG recordings shown in Fig 6 correspond to the mixed breed when electrolyte gel was applied at the stainless steel dry electrode interface without shaving hair.

The frequency response of the ECG electrode-to-tissue interface was analyzed at different conditions. Electrochemical impedance spectroscopy (EIS) has been performed using a GAMRY Ref 600 Potentiostat. Fig 7 shows the real part of the impedance that is associated with the dissipation properties of the interface. It can be observed that the use of ECG patches requires hair removal in order to be able to record ECG signals. On the other hand, the pointed style stainless steel dry electrodes can be used without hair removal, and further enhancement can be achieved by applying gel electrolyte.

Accuracy of both ECG and PPG measurements can benefit from the availability of IMUs in our cBAN to enable adaptive motion artifact cancellation.

All animal procedures were consistent with NIH and USDA guidelines and were approved by the North Carolina State University Institutional Animal Care and Use Committee.

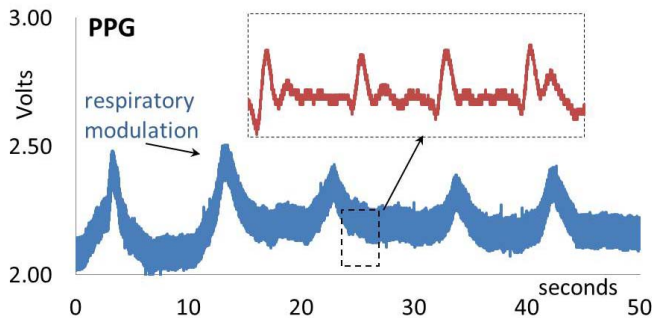


Fig. 5. Sample PPG signal demonstrates both heart beat and respiration related modulations. This PPG signal was recorded from a labrador retriever while in deep sleep.

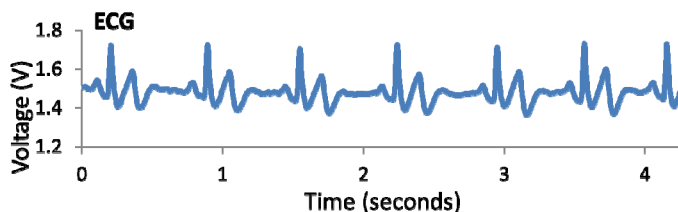


Fig. 6. Sample ECG signal recorded with pointed style electrodes and filtered with a second order notch filter centered at 60 Hz and a 100th order lowpass with a cut off frequency of 100 Hz.

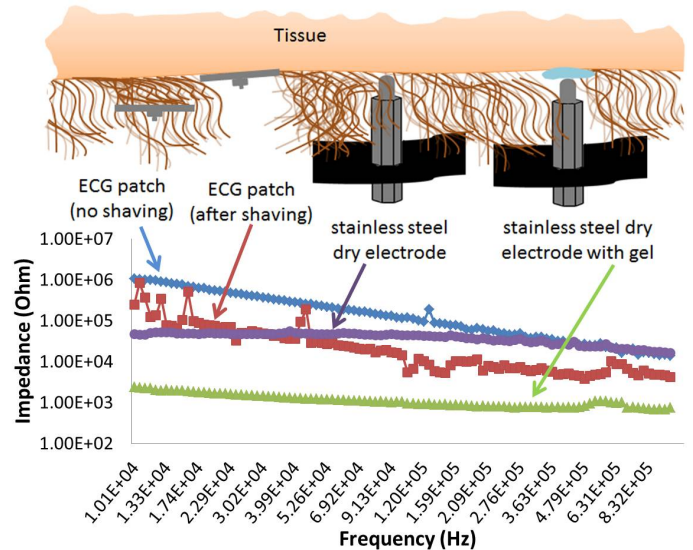


Fig. 7. Impedance vs Frequency response at the ECG patch and stainless steel dry electrode interface with tissue. Further enhancement in dry electrode performance with application of gel electrolyte.

IV. CONCLUSIONS

In this study we developed a novel non-invasive wireless system including biophotonic and biopotential sensors for continuous monitoring of canine vital signs (heart rate, heart rate variability and respiration rate) as part of the cBAN. This system allows handlers, pet owners and veterinarians to have continuous assessment of canine welfare, which can be of significant importance when working dogs are performing tasks in harsh environments. The combination of vital signs and canine body language recognition can be used to provide more subjective interpretation of canine emotional response to external stimuli and environments.

The proposed system is embedded on a chest strap and overcomes the limitations imposed by the hair layer by using pointed style stainless steel electrodes for ECG and light pipes for efficient optical coupling to the skin. This along with the wireless capability make this device ideal for daily use.

The system has been tested on two canines, a Labrador retriever and a large size mixed breed. Additionally, electrochemical impedance spectroscopy analysis was performed to compare and evaluate the tissue-electrode interface when ECG patches and stainless steel dry electrodes were used.

Further enhancement of the optical coupling of light into tissue using fiber optic bundles is an ongoing work and alternative electrode locations, like the neck, will be explored.

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