Smart Pet Clothing for Monitoring of Health and Mood

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***Abstract*— A smart pet clothing with full hardware and software support for internet of things is proposed. The hardware comprises three parts: a special pet sensor, an analog front-end circuit for detecting electrocardiogram (ECG) and breath signals, and a micro printed circuit board with signal communication. The software also consists of three parts: an algorithm for biosignal processing, an application (app) as graphical user interface (GUI), and a web server for healthcare. The algorithm is used to calculate the heart rate (HR), HR variability (HRV), high-to-low-frequency ratio determined by HRV analysis, breath rate, and basic emotion analysis. The app is developed for building a user-friendly GUI and communication platform between the hardware device and the cloud server. The web server not only provides detailed information to the veterinarian and the pet owner but also runs a convolutional neural network algorithm on big data to identify abnormal ECG signals. The analog front-end circuits with ECG and breath detectors, an ARM Cortex M0 MCU, and Bluetooth and power modules are integrated into a device with the size of a coin that can be placed in an approximately 32 mm × 32 mm × 24 mm box. The mechanism can be easily worn on clothing for monitoring pet health and mood.**

Keywords—Pet's healthcare system, electrocardiogram, breath, internet of things, wearable device, convolutional neural network

I. Introduction

Wearable smart devices coupled with sensors are now applied in mobile healthcare for humans. However, no realistic application focuses on pet healthcare. The global pet population has been increasing. According to data on the typical profile of pet owners from the US Census gathered by a survey conducted

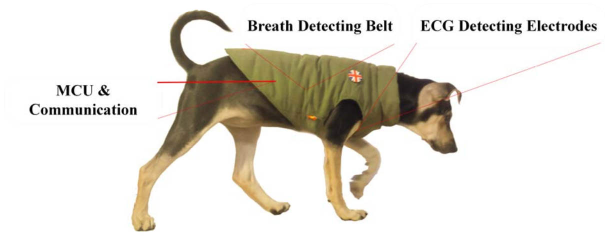

Fig 1. Smart pet clothing

by the American Veterinary Medical Association [1], the pet dog population has reached 70 million, and the percentage of households with pet dogs has reached 36.5%. Pet-related industries, such as pet care (e.g., groomers), pet shops, and veterinary medicine, have grown more quickly than any other industry. From 2000 to 2010, employment in pet-related industries grew by more than 30% locally and nationally, thus reflecting growth of the pet population and increased spending per pet by households. Pet ownership has been rising, but owners cannot always completely understand the physical and psychological conditions of their pets. The demand for this understanding in time is becoming increasingly important for pet owners. The proposed smart pet clothing allows owners to understand the emotions and health of their pets and take care of them effectively.

Heart disease in pets was the target issue in a previous work [2]. According to a conservative statistical report, 11% of dogs and 15% of cats suffer from symptoms of congenital or aging-

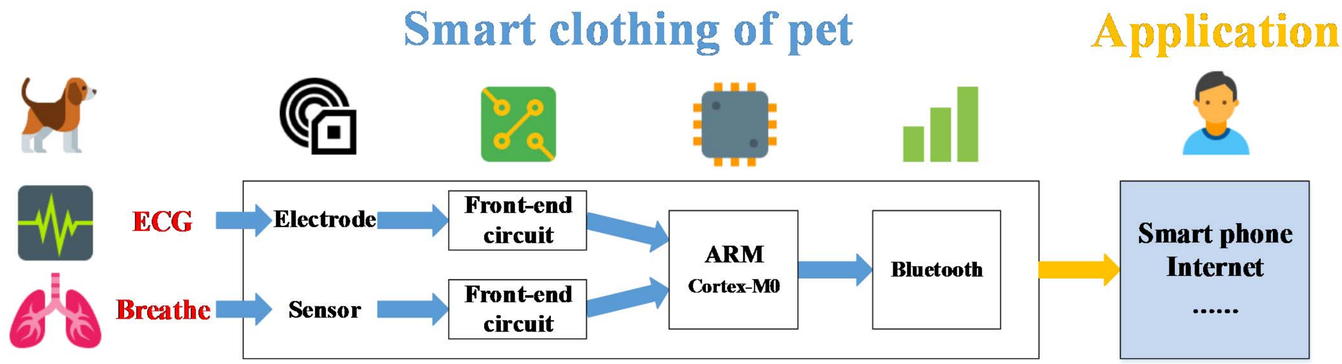

Fig 2. System block of wireless biosignal acquisition of pet and its application

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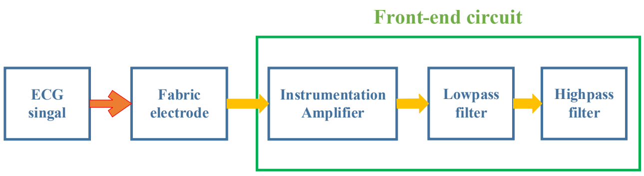

Fig 3. Front-end circuit block of implemented ECG acquisition

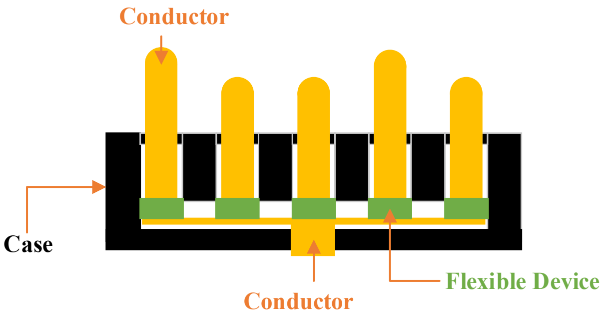

Fig 4. Structure of proposed ECG electrode

related heart disease. For instance, aged cats often suffer from hypertrophic cardiomyopathy, and aged dogs commonly have valvular stenosis and insufficiency. Moreover, certain heart diseases, particularly in cats without evident clinical symptoms, probably cause sudden death. Therefore, early detection and long-term tracking might be necessary.

This paper presents a smart pet clothing technology that monitors the health and mood of pets [3] by measuring electrocardiogram (ECG) [4]–[5] and breath signals. This mechanism can diagnose possible cardiovascular diseases in pets through ECG signal analysis. Combined with breath signals, the emotional response of pets can be understood. The rest of this paper is organized as follows. Section II describes the system architecture of the smart pet clothing. Section III presents the experimental results, and Section IV concludes the paper.

II. System Architecture

A. *System overview*

Applying a front-end sensor on the body of a pet for ECG signal detection is an obstacle that should be overcome. Pet hair interferes with the detection of biosignals. To address this problem, a special design is required for the front-end detecting circuit and electrodes. The proposed smart pet clothing is shown in Fig. 1. The mechanism should be structured such that it does not hinder normal pet activity. Moreover, the pet should be able to wear it comfortably at any time, and the physical structure of the clothing should be able to withstand pet sports.

The remote two-way communication system on the smart pet clothing is composed of two modes: active and normal modes. Under normal mode, the smart pet clothing instructs the system to conduct measurements every once in a while and sends the result to a smartphone by Bluetooth Low Energy (BLE). If the result is irregular, the smartphone launches warning signals through an application (app) to allow the pet owner to react as needed.

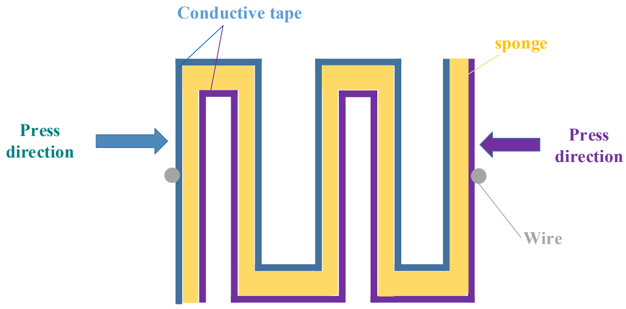

Fig 5. Frame diagram of breath sensor

If the owner wants to know the situation of their pet, they can switch to active mode, in which the smartphone instructs the clothing mechanism by BLE to conduct measurements on demand. The biosignals are also transmitted to the smartphone by BLE. The record of the physical situation of the pet can be traced by a veterinarian and allow latent diseases to be detected early. Those records can also support healthcare for chronic diseases. Furthermore, the global positioning system feature on the smart pet clothing can prevent the pet from being lost.

B. *Physical structure and circuits*

The proposed system architecture of the smart pet clothing is shown in Fig. 2. This work refers to a paper that mentions a complete biosystem in designing the smart pet clothing system [2]. The proposed mechanism measures ECG and breath signals using a well-designed electrode and sensors. The signals are processed by the installed front-end circuits and calculated by the microprocessor to obtain information about the mental and physical health of the pet. Moreover, the smart pet clothing uses BLE and mobile internet to transmit information to the app on the smartphone of the owner. Each component is briefly described in the succeeding sections.

Fig. 3 shows the structure of the front-end ECG circuits, which comprise an instrument amplifier and two filters. First, the instrument amplifier cancels the common-mode noise from inputs and amplifies the biosignal. Then, the biosignal goes through a high-pass filter with a bandwidth of 0.5 Hz and then a low-pass filter with a bandwidth of 55 Hz, thus capturing the desired ECG signal.

Fig. 4 shows the special ECG electrode, which is made of several copper bars that form a matrix for detecting the desired signal. Each copper bar is connected with a flexible spring, which can lighten the compression of skin and clothing and avoid pricking the pet. The copper bars can be connected together with a piece of sheet metal (similar to a conducting wire) that is affixed to the bottom of a 3D-printed pedestal. This electrode can reduce interference from pet fur, thereby allowing ECG signals to be detected easily and clearly.

A frame diagram of the breath sensor is shown in Fig. 5. The sensor is a capacitance formed by two conductive types with a sponge between them. When pressure is applied on the sensor, its resulting deformation causes a change in capacitance. The breath sensor can be attached to the chest of the pet to record every upward and downward movement, which is accompanied with respiration.

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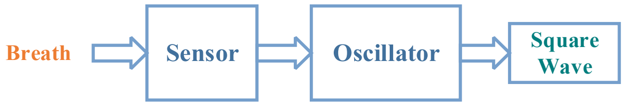


Fig 6. System block of breath detection

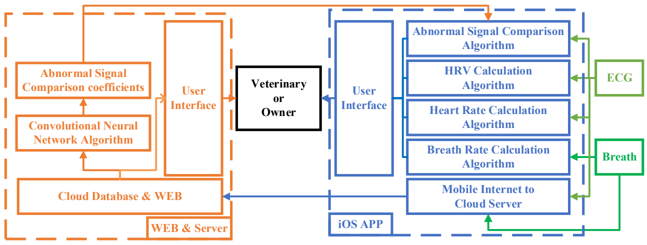


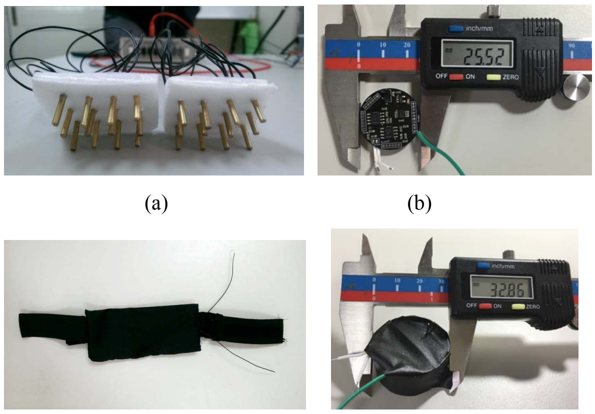
Fig 7. Software system structure

Fig 8. Smart pet clothing sample

Fig. 6 illustrates the structure of the sensor that detects the breath signals. Breath frequency can be derived from the frequency change of the oscillator because the frequency of the RC oscillator varies by the capacitance caused by respiration. Moreover, the microprocessor collects and converts signals into simple information and activates BLE and mobile internet to send information about the pet, such as location, to the owner regularly or on demand. The miniaturized printed circuit board (PCB) process is used to reduce the area occupied by the circuits. The micro PCB can be placed into clothing without limiting or hindering the mobility of the pet.

C. *Software development*

Fig. 7 shows the proposed software development system, which consists of two subsystems: an app graphical user interface (GUI) and a cloud database with web GUI. The iOS app system has a built-in timer that can launch an internal measuring system that detects the physiological signals of the pet. Meanwhile, the ECG signals are processed by four algorithms. An abnormal signal comparison algorithm is used to detect unusual signals. These irregular signals are shown on the app. Heart rate (HR) and HR variability are also calculated and shown on the app to help the veterinarian diagnose heart disease and inform the owner about the physiological state of their pet. ECG and breath signals are transmitted to the cloud database by mobile internet. The physiological information of the pet is displayed on the web GUI, and the ECG signals are processed by a convolutional neural network (CNN) algorithm [6] to obtain the coefficients of the abnormal signal. The coefficients are then returned to the iOS app for an adjustment of the abnormal signal comparison algorithm [7], thereby making the algorithm suitable for analyzing unusual signals.



(a) (b) (c) (d)

Fig 9. Physical structure and circuits: (a) proposed ECG electrode, (b) implemented PCB module, (c) breath detection belt, (d) pocket with PCB modules

III. Experimental Result

Fig. 8 shows a measured scenario with a live dog used to verify the proposed system. The pocket on the back of the pet includes a PCB module with ECG and breath sensors, an ARM MCU, BLE, and power module. The test is conducted ten times on a small Maltese dog as follows.

A. *Proposed physical structure and circuits*

The ECG electrode, which is shown in Fig. 9(a), comprises several bar coppers and a pedestal. Each bar in an array of bar coppers used as electrode can detect ECG signals while avoiding interference from fur. Fig. 9(b) shows the proposed circular PCB module with a diameter of 25.52 mm. The breath detection belt is shown in Fig. 9(c), and the results obtained by the breath detection system is shown in Fig. 9(d). Breath variation can be detected by the difference in frequency caused by varying capacitance values. To reduce the noise from the long wiring, this work uses a 3D printer to develop a pocket, as shown in Fig. 9(d). The pocket is a cylinder that measures approximately 32 mm × 32 mm × 24 mm. The measured ECG and breath signals are shown in Fig. 10.

B. *Proposed software system*

This research develops an iOS app exclusively for pet healthcare, as illustrated in Figs. 11 and 12. This study also develops an algorithm applied in the app. The interface displays original and breathing rate. The app not only helps the veterinarian easily diagnose pets but also allows the owner to preliminarily understand the situation of their pet. Meanwhile, this work builds a cloud database and a web GUI. The cloud database can receive real-time physiological data about the pet from the app and display it on the website, as illustrated in Fig. 13.

This study uses a CNN algorithm to improve the precision of anomalous ECG signal detection. The algorithm needs big data to train for anomaly detection. In terms of the data, 30 points are adopted before and after the R peak; thus, 61 points from the ECG signals are used as features for training the CNN.

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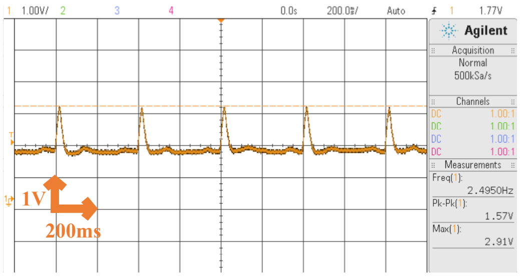
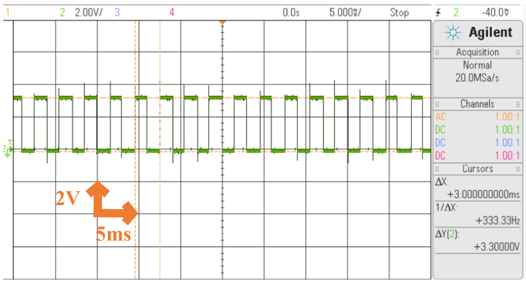


(a)



(b)

Fig 10. (a) Measured result of ECG signal, (b) measured result of breath signal

TABLE I. PERFORMANCE COMPARISON

	This work	2016[3]
Measuring target	ECG & Breath	ECG & PPG
Electrodes	Dry electrodes	Dry electrodes
Volume	Smaller (32mm×32 mm×24 mm)	Bigger
Communication	Bluetooth	Wi-Fi
Userinterface	WEB & APP	Computer
Machine Learning	Y	N

However, the database does not contain enough pet ECG signals for the algorithm; therefore, this work applies the MIT-BIH database [7] to validate the model and achieve 98% precision. After the model is fitted, the parameters of the model are extracted and transmitted to the app to maintain an acceptable level of precision.

IV. CONCLUSION

The physical structure and software of the proposed system are finished preliminarily. Biosignals are detected accurately and can be transformed into useful data using the developed algorithm. The data is sent to the cloud, and the information of users are systematically arranged to enhance system usability. In the future, the CNN in this study will be utilized with ECG signals from a live pet and an accurate abnormal signal comparison algorithm will be developed.

The most important purpose of developing this technology is improving human life. Complex thoughts and functions can be transformed into simple principles and a user-friendly interface by thoughtful design and creativity. The proposed smart pet clothing can allow veterinarians and pet owners to understand the physical and psychological conditions of pets. In addition to shortening the distance between individuals who live alone, such as the elderly, and other pet owners and their pets, the smart pet clothing also prevents pets from being lost. Furthermore, the proposed technology can be applied to police

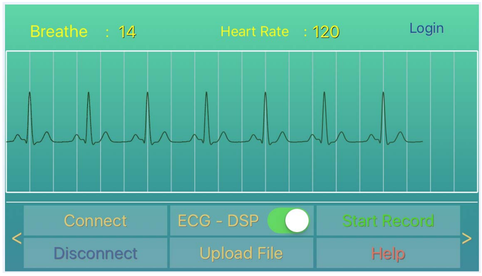


Fig 11. Developed iOS app screenshot (Static State)

Fig 12. Developed iOS app screenshot (Actual Sport State)

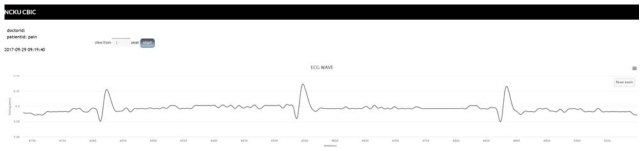


Fig 13. Developed website screenshot

and guide dogs. This thoughtful design for pet clothing significantly changes the interaction pattern between humans and their pets. This innovation is also predicted to improve convenience.

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