A Non-Invasive Wireless Respiratory Monitoring System for Animals

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*Abstract*—This paper presents and assesses the device of an undergraduate engineering research project. We explain the purpose and need for such a device. Next, we describe the design and construct of the device. In addition, we describe the test plan, setup, and result of the device. We comment on the future improvement and development of the device.

# Introduction

The main objective of the project is to develop a biomedical device that can noninvasively monitor a dog’s heart rate using conductive fabric.

There has been much progress in wearable sensors for animal monitoring in terms of technology and applications. The latest technologies include RFID tags, implants, and other non-invasive methods. On the application side, these wearable sensors are able to detect animal sweat constituents, measure body temperature, observe behavior and movement, detect stress, analyze sound, detect pH, prevent disease, detect analytes and detect presence of viruses and pathogens, according to an article on sciencedirect.com[1]

Along with the advancement of technology there is also an increase in demand for wearable monitoring devices for animals in pet industry, animal husbandry and animal protection fields. According to Wearable technology for animals 2017-2027: Technologies, Markets, Forecasts [2], “The animals most likely to employ wearable electronics in volume in the next decade are those controlled by humans notably certain livestock, work animals and pets that we identify but conservation of wild species will also increase in number and sophistication.” One specific field of application we are looking into is the animal monitoring studies for neuroscience and psychology. Numerous researches have shown a relationship between respiratory activities and psychological activities in human beings. According to an article on ScienceDaily[3], “There's increasing physiological evidence connecting breathing patterns with the brain regions that control mood and emotion. Now researchers have added neurons associated with the olfactory system to the connection between behavior and breathing. Connecting patterns in these interactions may help explain why practices such as meditation and yoga that rely on rhythmic breathing can help people overcome anxiety-based illnesses.” Another article: Respiratory Changes in Response to Cognitive Load: A Systematic Review [4] published on the NCBI website also indicates the existence of such relationship. Therefore, we believe that such relationship not only exist in human beings but also in various animals and they are definitely worth looking into. A reliable wearable apparatus for real time animal respiratory monitoring can certainly be beneficial for this kind of research.

The recent advancement of conductive fabric opens up a brand-new approach to the development of wearable monitoring devices. There are already numerous types of conductive fabric materials available on the market, such as pressure sensitive conductive rubber and metal coated woven fabric that can be constructed as capacitive sensors. Several applications have already shown their potential in wearable technology. In our case, these fabrics can be constructed as sensor to capture animal chest movement.

There are numerous other breathing and heartbeat monitoring techniques as well. As mentioned in an article publish on MDPI.com [5], “These techniques include direct contact such as magnetic induction, microphone, and capacitive, and indirect contact (contactless) such as electromagnetic radar detection, laser radar detection, ultrasonic radar detection, thermographic imaging, and video camera imaging.” Compared with their method our approach is simpler and more economical.

The same technology can be applied in heartbeat monitoring as well. Studies have shown that there is a certain relationship between breath rate and heart rate. According to article THE RELATION BETWEEN RESPIRATION AND THE PULSE-RATE,[6] “IT is well known that a close relationship usually (though not invariably) exists between the degree of activity of the respiratory centre and the rate of the pulse.” While there is no quantitative conclusion at this point it is definitely possible to obtain the heart rate by measuring the breath rate in the future.

Our device can really simplify the dog breath rate sensing technology making them more affordable and reliable animal psychological studies. The approach towards this project is to measure the breadth rate of a dog which is related to the movement of the dog’s chest. The resistance of the fabric will vary as the dog’s chest stretches the fabric. Using resistance to voltage convert circuitry, we generate a voltage signal that is correlated with the movement of the dog’s chest. This signal is captured using a microcontroller and then together with the temperature readings from a temperature sensor they will be sent over to a computer wirelessly for further process and analysis. This custom-made sensor-microcontroller device is attached to a dog harness. Finally, in our computer, we would filter out all the noises and measure the number of pulses which represents the breath rate and ultimately heart rate from the signal. The recorded data can be used in analyzing, diagnosing and improving the dog’s health conditions.

# Design and Construct

## Hardware

The device mainly consists of a rubber cord stretch sensor, a microcontroller with a Wi-Fi module, a temperature sensor, a 350mAh battery and a dog harness.

1. List of hardware

| Item | Name | Spec |
| --- | --- | --- |
| Stretch sensor | ConductiveRubber Cord Stretch Sensor (from Adafruit) | Length: 39 inches Diameter: 2mm Resistance: 350-400 ohms per inch / 140 - 160 ohms per centimeter |
| Microcontroller | Adafruit HUZZAH32 – ESP32 Feather Board | CPU: 240 MHz dual core Tensilica LX6  RAM: 520 KB  Flash menmory: 4MB  I/O:  3 x UARTs  3 x SPI  2 x I2C  12 x ADC  2 x DAC  2 x I2S  802.11b/g/n HT40 Wi-Fi  Bluetooth (classic and BLE) |
| Temperature sensor | DS18B20[7] | Temperature range: -55 to 125°C  Resolution: 9 to 12 bit  Interface: 1-Wire interface |
| Battery | Lithium Ion Polymer Battery[8] | Weight: 7.9g  Dimensions: 36mm x 20mm x 5.6mm  Output: 350mAh at 3.7V nominal​ |
| Misc | 3D printed container case,  Dog harness |  |

The stretch sensor mainly facilitates the function of capturing the dog’s chest movement. We selected ESP32 as our microcontroller mainly because of it’s abundant I/O and wireless options. Such that it gives us plenty of implementation options. In the final version of the device we used an ADC on pin A3 for the stretch sensor and a digital pin A0 for one wire interface of the temperature sensor. The battery was selected mainly based on its dimension, so that it can be fit into the 3D printed case. While under the dimension limit we choose the battery with the largest capacity. The 3D printed container case was used to house the device and fix it on the dog harness, and the dog harness allow us to mount the whole device on the dog. The temperature sensor DS18B20 was added on as an auxiliary function to get a comprehensive study on the test subject.

The stretch sensor will be tightly wrapped around the test subject’s chest and capture the expansion and contraction movement as an electric signal which will then be sent to the microcontroller through pin A3. The microcontroller is an ESP32 by Espressif Systems. [9] It is responsible for compiling the data and send them to PC via Wi-Fi. The code can be found on my GitHub repository, and they can be loaded into the microcontroller through Aduino IDE [10]. In addition, creating and enable a Wifi hotspot on the working PC with name “Dog\_temp”, and a password “12345678” to work with my code. The program was supported by the Adafruit ESP32 library, detailed instruction can be found on their website. [11] The data was later received and processed by MATLAB. The MATLAB program will smooth the signal from the stretch sensor and count the number of pulses which is the indication of the dog’s chest movement. And through that we are able to get the dog’s breath rate. The whole device was mounted on the dog harness. This code can be found on GitHub as well. [9]

## Software

The microcontroller program is responsible for data logging and transmission.

On microcontroller start up the program will seek to connect to the hotspot created by the laptop. Once the connection is established it will wait for the FTP connection request from the MATLAB program. Once the FTP communication established the MATLAB program will start sending command to request either temperature reading or stretch sensor, and the microcontroller will send back the requested data accordingly.

The PC software was written in MATLAB which contains 3 stages. Noise filtering, peak counting, and result in plotting and logging.

It starts off by requesting FTP connection to the microcontroller. Once the connection is established the will continuously sending stretch sensor reading request during the measurement period and request one temperature reading at the end of the measurement. The measurement time can be specified in the user interface. After the signal is acquired, the MATLAB program will filter out the noises and count the number of pulses in the signal. The MATLAB has a function called *findpeaks()* to facilitate the pulse counting in the signal. Finally, the program will calculate the average breath rate for the measurement period. The result will be presented both in a graph and a file.

# test set up and results

The tests were separated into 2 stages: the first one being the electrical functionality test; the second one being the biological test on a test subject. The common start up procedure include: 1) start the hotspot; 2) turn on the microcontroller; 3) start the MATLAB application and start measuring.

## Stage one electrical function test

In the first stage, we will power on the device and manually stretch the sensor for 15 seconds. In these tests, we seek to verify whether the sensor sensitivity is good enough for the MATLAB to find peak algorithm to count the number of pulses. Also, we verified whether the BLE data link is properly working.

In the graph, the blue line on the top shows the original signal and the red line at the bottom shows the filtered signal. We can see 37 out of 40 pulses were successfully identified which is a correction rate of 92.5%. We can conclude that the system work with a rather good accuracy.

## Stage two biological test

In the second stage, the test included a test subject (a golden retriever) provided by A Nickerson. During the test, we strap the dog harness with the device onto the test subject and measure the breath rate for a certain amount of time. We conducted 2 groups of tests.

In group one we conducted the experiment with the dog being idle and take the measurement for 15 seconds.

In the graph, the blue line on the top shows the original signal and the red line at the bottom shows the filtered signal. The filtering did smoothen the signal by quiet a bit. The program picked up 9 additional peaks which is not caused by dog breathing activity in the first plot. In the second plot the algorithm picked out 38 peaks while the actual signal only contains 25 pulses.

In the second group, the dog can move freely, and we take measurements for 60 seconds.

In the graph, the blue line on the top shows the original signal and the red line at the bottom shows the filtered signal. In this group due to the ambiguous nature of the signal, we are not able to identify any pulses created by the breathing activity. The reason for such signal being the movement of the dog would also stretch the rubber cord stretch sensor causing mechanical disturbances on top of dog’s chest movement.

# discussion and summery

In this project, we developed a wearable breath rate sensor with a wireless communication capability for dogs. We demonstrated our capability to collect breath rate data and transmit them through Wi-fi. The electrical function test and group one of the biological tests were completed with good results. However, due to the non-idealities of the signal measured from the dog, such as muscle movement, device vibration or any form of an unexpected stretch of the rubber will cause a disturbance, thus resulting in inaccurate measurement of breath rate. We would still need to further improve our signal processing of the raw data and the pulse recognition and counting mechanism. In addition, we can potentially, fix the problem by adding accelerometer for compensation. As the continuation of this work, aside from the improvement previously mentioned, we will be adding more diagnostic tools for measuring dogs’ heart rate. Such as measuring heart rate variability of a dog.

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