Thermistor-based Breathing Sensor for Circadian Rhythm Evaluation

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ABSTRACT

One of the most frequently used methods to sense breathing pattern is to detect airflow using a nasal thermistor or a thermocouple sensor. Prolonged, minimally intrusive measurement of the breathing pattern is particularly important for polysomnography, sleeping disorders, stress monitoring, biofeedback techniques, and circadian rhythm analysis. Although most applications require only breathing pattern, some applications and diagnostic procedures require monitoring of the rhythm of change of dominant nostril. In this paper we present our design of a differential thermistor-based breathing sensor for prolonged monitoring during the normal activity. The system is designed using a low power microcontroller Texas Instruments MSP430F149 with an on-chip A/D converter for data acquisition and signal processing. We use wireless RF link to a PC for long-term data acquisition and storage. Precise measurement requires decreasing zero and sensitivity errors of the measurement. We discuss signal processing methods, calibration and parameters used to characterize breathing patterns necessary for circadian breathing rhythm evaluation.

Keywords: *breathing, sensor, thermistor, wireless, intelligent sensor, monitor, circadian.*

1. INTRODUCTION

Reliable long term monitoring of human respiration is crucial for a number of medical conditions requiring circadian rhythm analysis [1], including sleep-related breathing disorder [2][3], hypertension, ischemic heart disease, heart failure, and stroke [4]. We plan to investigate circadian breathing rhythms and their correlation with physiological indicators of the state of autonomous nervous system, as well as stress induced changes in breathing rhythms. Many biochemical and behavioral variables show a 24-hour periodicity, including changes in blood cortisol, growth hormone, melatonin and body temperature. It has been shown that the respiratory chemoreflex response exhibit circadian rhythms independent of metabolic rate [3].

Thermistor based sensors are now considered invasive for a new generation of breathing sensors [5][6]; however, thermistor based sensor was inevitable in our case, since we plan to monitor left/right breathing activation (rhythm of change of the dominant nostril). Our experimental prototype was developed as a wireless intelligent sensor in a personal area network of physiological sensors to allow subject's mobility outside of home or laboratory [7]. Sensor intelligence allows data upload whenever link to the PC server is available.

In this paper we present system design and application issues. We discuss signal processing methods, calibration and parameters used to characterize breathing patterns necessary for circadian breathing rhythm evaluation.

2. BREATHING SENSORS

Traditionally, breathing sensors include transducers attached to the human body. For example, commonly used method uses two elastic bands embedded with sensors around the ribcage and abdomen to monitor their movements [8]. Information on the separate motions of the ribcage and abdomen provide information about respiration effort. Although acceptable for shorter periods of time, this method is unacceptable for long term monitoring or monitoring of sleeping patients. As an alternative, the air-mattress system features multiple air compartments to monitor movements of the thorax and the abdomen separately [5][6]. Other methods include microwave [10], electrical impedance, pressure sensitive pads, and static-charge-sensitive beds. A varying degree of success of these sensors is reported. The main shortcoming of these methods for our research is that they provide only a single channel output.

An ultrasonic breath measurement system is based on the phase shift reconstruction principle. The patient’s chest wall movement caused by breathing can be detected with high precision and without contact [10]. Photoplethysmograph (PPG) could be used even in bath, with waterproofed probe attached to the bottom surface of an inner wall of a bathtub [9]. Respiration components are extracted from the signal after filtering.

3. WIRELESS INTELLIGENT BREATHING TELEMETRY SENSOR WIBRATE

3.1. Principle of operation

Thermistor based sensors detect change of breath temperature between ambient temperature (inhalation) and lung temperature (exhalation). A thermistor placed in front of a nostril detects breathing as a temperature change. It is configured in a bridge with fixed resistors used as a reference. Differential amplifier is used to amplify the signal difference. Figure 1 presents five breathing cycles recorded on one channel.

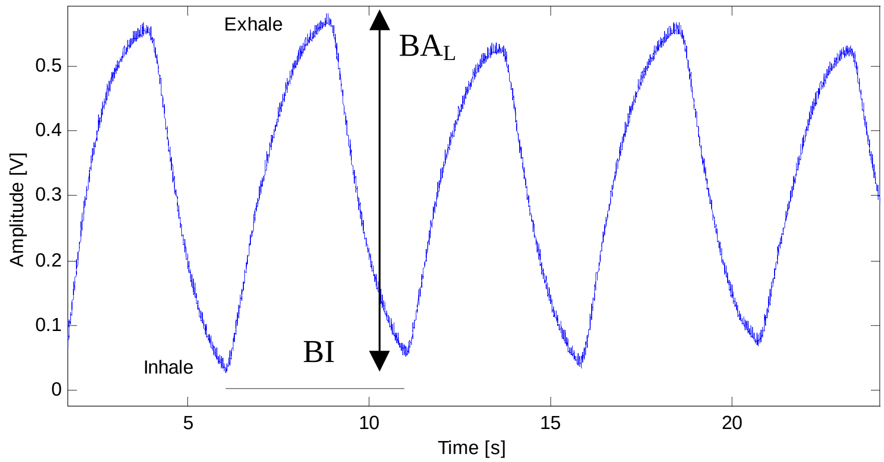

Figure 1. Single channel breathing signal; BA_L – left nostril breath amplitude; BI – breath interval.

3.2. System organization

Existing technology allows implementation of the proposed sensor in less than 20 mm^2. However, program development requires much more flexible environment. Therefore, we use our custom developed wireless intelligent sensor – WISE [7]. The system is designed using a low power microcontroller Texas Instruments MSP430F149 with an on-chip A/D converter for data acquisition and signal processing. Our prototype environment is presented in Figure 2. We use wireless RF link for long-term data acquisition and storage, and standard RS232 link for program development and parameter setting.

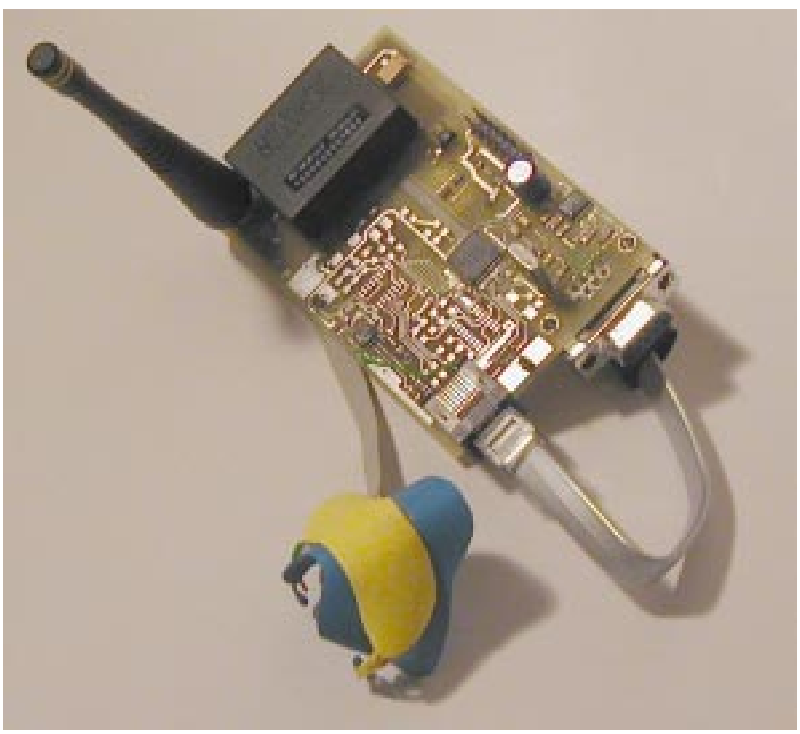

Figure 2. Wireless Intelligent Breathing Telemetry sensor (WIBRATE)

Precise measurement requires zero offset and individual thermistor sensitivity compensation. We implemented a very simple calibration procedure. Steady state, ambient temperature measurement is used to compensate DC offset of individual thermistors in software rather than bridge resistor calibration. Thermistor sensitivity is compensated with the scale factor calculated using test run breathing with both thermistors in front of one nostril.

Automatic signal analysis extracts the following parameters:

- *Breathing amplitude* is calculated for every breathing cycle as a difference between minimum (Inhhalation) and maximum thermistor voltage (Exhalation) during the given cycle. Separate values for left (BA_L) and right (BA_R) nostril are calculated.
- *Breathing interval* is measured between two minimums representing two inhalations. We currently use 120 Hz sampling rate.
- *Breathing frequency* is calculated from the breathing interval as a number of breaths per minute (60/BI). Normal breathing frequency is 12-20 cycles/minute.
- We are particularly interested in monitoring of left/right nostril activation cycles. Therefore, we use *index of symmetry* as a measure of their relative activation:

$$IS = (BA_L - BA_R) / (BA_L + BA_R)$$

WIBRATE maintains the following parameters for each breath in one record:

- Status
- Breathing amplitude (BA_L and BA_R)
- Beginning of the interval (time)
- Breathing interval
  - Inhale interval
  - Exhale interval

Status is maintained for each breath. We currently maintain the following status:

- *Normal* is every breath lasting more than 0.5 seconds, with amplitude larger than 10% of calibrated breathing amplitude during normal breathing.
- *Apnea* is cessation of breathing for more than 10 seconds. Sleep apnea can last more than 120 seconds.

Proposed solution is prone to errors in the case of mouth breathing. We plan to combine chest strap to record breathing effort to improve the quality of processing.

Figure 3. WIBRATE measurement

Typical record contains 8 bytes (without data compression). Therefore, limited memory capabilities of our microcontroller allow storage of up to one hour of basic information. In our settings it is more than enough to compensate for bad connection quality, errors in signal transmission, and out of range condition.

4. CONCLUSION

We implemented WIBRATE prototype as a development environment for circadian analysis of breathing. A differential thermistor-based breathing sensor with the low power microcontroller is used for prolonged monitoring during normal activity. Device intelligence allows sophisticated real-time digital signal processing, while wireless RF link to PC facilitates long-term data acquisition. WIBRATE stores the acquired information locally and scans the quality of wireless link. Stored data set is uploaded periodically, without user intervention, when the wireless link of good quality is available. This significantly increases the scope of normal activity during circadian breathing rhythm evaluation. We are currently in the process of IRC approval for the larger study to collect data about individual circadian variability of index of symmetry.

5. REFERENCES

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