Respiration-Rate Monitor Based on Temperature Sensors: Electronics and Processing

Project Report

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Sincerely,

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Abstract

The irregular respiratory rate significantly predicts possible clinically severe occurrences, such as cardiac arrest and other respiratory chronic. That said, even when respiratory illness is the patient's primary issue, many hospitals have inadequate respiration rate recording. This study details the creation of an intelligent system based on a microcontroller that can calculate and continuously monitor a patient's respiration rate in real-time.

Monitoring the amplified voltage difference (differential amplification) across temperature sensor corresponding to exhaled and inhaled air temperature is the principle underlying the system's development. A microcontroller continuously calculates the breathing rate by recursively executing a FFT method in real-time.

Introduction

Along with blood pressure, body temperature, and pulse rate, respiratory rate is one of the four vital indicators commonly used to monitor patients in acute hospital wards. An irregular respiratory rate significantly predicts severe clinical occurrences. In hospital wards, the most significant indicator of cardiac arrest is a respiratory rate of more than 27 breaths per minute.

As a result of respiration, the air undergoes four changes: temperature, moisture content, chemical composition, and volume. In most situations, the air exhaled is 2-3°C warmer than the air breathed. The temperature of the exhaled air is approximately 28° C (82.4° C), whereas the inhaled air is at ambient temperature, which is typically around 25° C (70° F). The less heat the body loses during breathing, the warmer the inspired air is.

Out of the four changes, the "change in temperature" is the one that can be parameterized with the least amount of complexity, making it useful as a tracking parameter of its physical value and interpretable analytically, providing the most information. This is because the periodicity involved in the temperature plot is quite vivid, which we shall encounter later. Moreover, it involves dry (non-wet) sensing techniques. The current project's goal is to use temperature sensors to create an intelligent system based on a microcontroller. The device monitors the respiration rate. The system has been designed to be affordable, portable, and easy to use.

Sensor Electronics and Interface

The scheme shown in *Figure 1* is employed to capture the temperature changes between the inhaled and exhaled air.

As clearly apparent, the electronics involve three major components:

- DC Offset Remover and Amplifier
- Filters
- Microcontroller Interface

Each of these modules plays critical role in signal conditioning and enhancement.

Temperature Sensor

The current work uses 100K NTCLE413 thermistor for monitoring the exhaled air temperature. It does not involve any linearising circuitry. Features such as accuracy down to ± 0.3 °C and small body of at most 3 mm for easy installation, makes it a suitable choice. It has tolerance of ±3 % at room temperature. The sensor is expected to be operated in normal conditions, lets have it be 20°C - 30°C, so an interfacing and linearizing circuitry is needed to process the temperature variations through electric signals.

This is achieved through 3-point linearization technique. The reference for 3 points is suitably chosen as:

Temperature	Resistance (Typ.)
20°C	126.087 kΩ
25°C	100.000 kΩ
30°C	79.808 kΩ

$$R_0 = \frac{R_2R_3 + R_1R_2 - 2R_1R_3}{R_1 + R_3 - 2R_2} = 78.7\text{k}\Omega$$

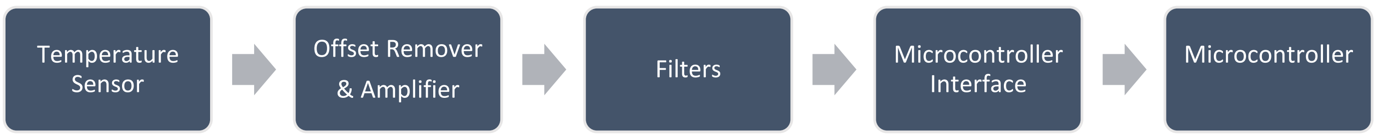


Figure 1: Block Diagram

Since the region of temperature operation is quite narrow, the linearizing resistance can have some tolerance, and thus choosing the standard resistance will be suitable choice.

$$R_0 = 82\text{k}\Omega$$

Finally, the senor is realized as shown in *Figure 2.*

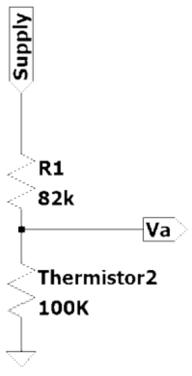


Figure 2: Temperature Sensor Block

Offset Remover & Amplifier

The temperature sensor realized will have a DC offset, which is undesirable during the amplification stage. So, the offset removal is carried out by the resistive bridge configuration and the differential amplification is achieved using instrumentation amplifier (AD620). (*Figure 3*)

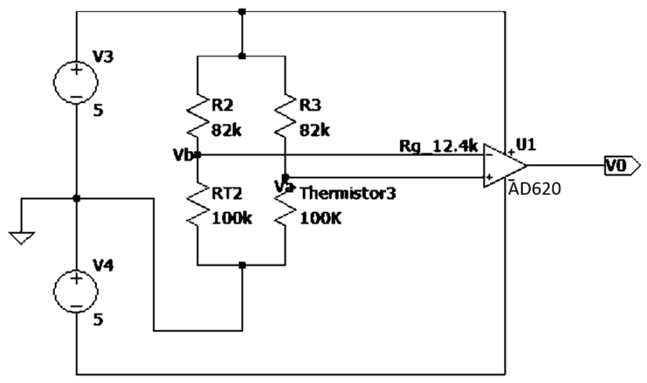


Figure 3: Offset Remover and Amplifier

This scheme also provides with a calibration point of V$_b$, in the sense that it is fixed to voltage corresponding to that at room temperature. The variation in V$_a$ is around $\pm 250\, mV$ maximum, which is given a gain of 5 to reach around 1.5V at the output V$_0$. The gain adjustment is done by varying the R$_g$ of AD620, and corresponding to a gain of 5,

R$_g$ = 12.4 kΩ (from datasheet)

Filters

To deal with the improper offset removal due to resistance tolerances and mismatch a High Pass Filter is used, and to deal with noise a Low Pass Filter is cascaded; thus, realizing bandpass filter.

Normal breath rate is 12-20 bpm which corresponds to a frequency of 0.20 Hz – 0.33Hz. Keeping into the buffer margin, the cut-off frequency of High Pass Filter is wisely chosen as 0.17 Hz and that of Low Pass Filter as 5 Hz.

To prevent the loading effects, active Sallen Key filters are used, for which OP07 best serves the purpose. (*Figure 4*)

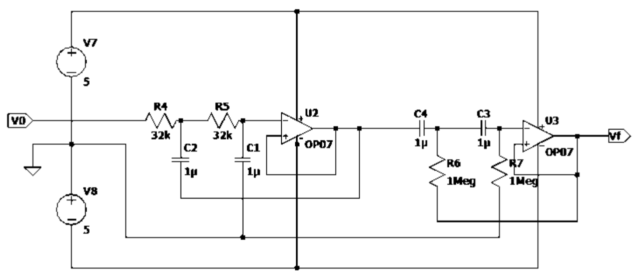


Figure 4: Filters

Cut-off frequency for both the filters is given as:

$$f_0 = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

And the corresponding quality factors lie in range of 0.5-0.7.

Microcontroller Interface

The signal received at V$_f$ is more or less an AC signal with mean zero. But the microcontroller, here Atmega328P (Arduino UNO), can process only the signals lying in range 0V-5V. So, the signal needs to be superimposed with a DC offset, for which an inverting adder circuit is used, to add an offset of -2.5V. (*Figure 5*)

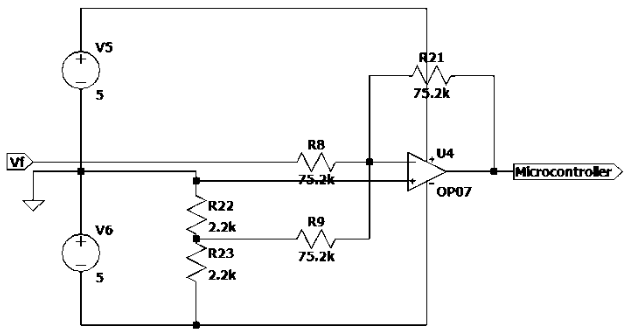


Figure 5: Microcontroller Interface

Finally, microcontroller receives the signal, with an offset of 2.5V.

This completes the scheme for Respiration Rate Monitor using the temperature sensor. (*Figure 6*)

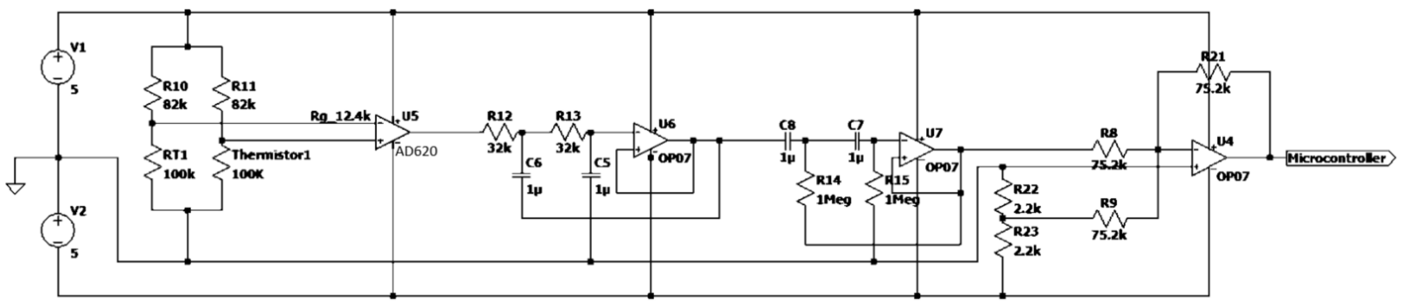


Figure 6: Signal Conditioning Scheme for Respiration Rate Monitor

Microcontroller

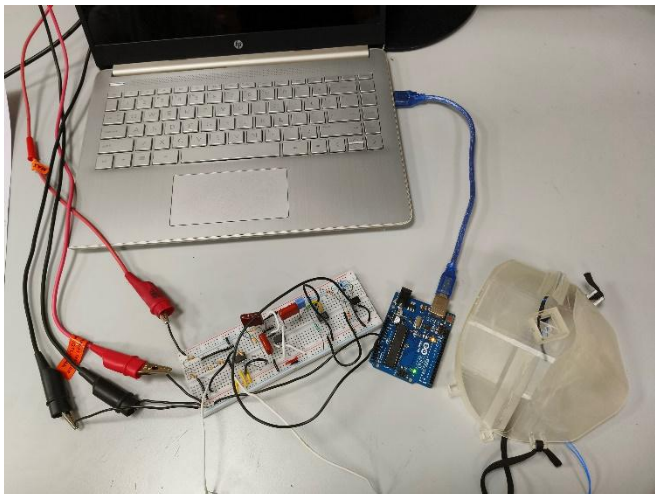
ATmega328P (Arduino UNO) is used to find the frequency of processed signal and thus compute the breathing rate. There exists a pre-defined library for Fourier Transform Computations, which is directly imported and used. In accordance with Nyquist Criterion the sampling rate is chosen to be 3 Hz, and sampling is done for 22 seconds. Finally, the breath rate per minute is computed. (*Appendix*)

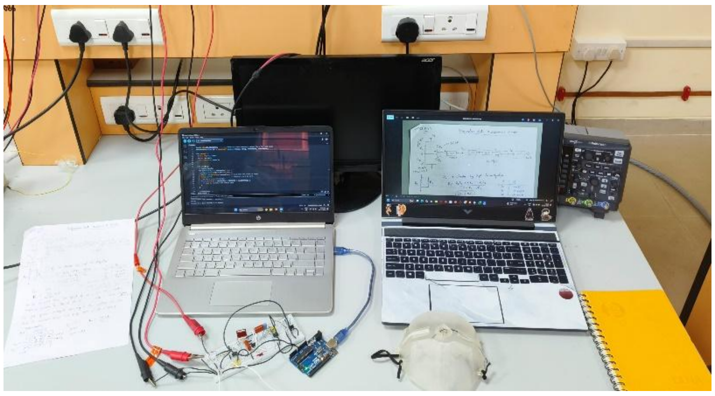
Conclusion

Sensor electronics is successively realized to obtain the respiration rate of the patient. The scheme is quite simple and systematic, working with a smaller number of components. Clearly the scheme is reliable and efficient. The thermistor is mounted on a mask, which is easily wearable, and thus the sampling can be done.

References

1. Real-Time Breath Rate Monitor based Health Security System using Non-invasive Biosensor Sumanta Bose, Student Member, IEEE; Prabu K; Dr. D. Sriram Kumar https://ieeexplore.ieee.org/iel5/6383183/6395857/06395957.pdf
2. Respective component datasheets.
3. Arduino Documentation.





Appendix

Microcontroller program: (C language)

```
#include "arduinoFFT.h"

const int analogPin = A0;       // Analog pin for input
const int sampleRate = 3;       // Sampling frequency in Hz
const int numSamples = 64;      // Number of samples (should be power of 2)
// result will be displayed after 64 samples are capture at rate of 3 samples per second
// hence 22 seconds to get final result
double vReal[numSamples];       // Array to store real values
double vImag[numSamples];       // Array to store imaginary values (zero for real data)
ArduinoFFT<double> FFT = ArduinoFFT<double>(vReal, vImag, numSamples, sampleRate);

void setup() {
  Serial.begin(115200);
  while(!Serial);
  Serial.println("Ready");
}

void loop() {

  // Taking Samples

  for (int i = 0; i < numSamples; i++) {
    unsigned long sampleTime = micros();
    vReal[i] = analogRead(analogPin); // Read data and store in vReal
    vImag[i] = 0;                    // Imaginary part is zero
    while (micros() - sampleTime < (1000000 / sampleRate)) {
      // Wait to maintain the sample rate
    }
  }

  //Perform FFT on the samples

  FFT.windowing(FFTWindow::Hamming, FFTDirection::Forward);   // Apply a windowing function
  FFT.compute(FFTDirection::Forward);   // Compute FFT
  FFT.complexToMagnitude();             // Compute magnitudes


  double x = FFT.majorPeak();
  Serial.print("Breath Rate (per minute) = ");
  Serial.println(x*60.0, 6);
  while(1); //run once
}
```