Temperature sensor based ultra low cost respiration monitoring system

Conference Paper · January 2017

DOI: 10.1109/COMSNETS.2017.7945448

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Temperature Sensor Based Ultra Low Cost Respiration Monitoring System

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***Abstract*—Measurement of respiration rate is a vital parameter for adequate health monitoring. An abnormal respiration rate can indicate a variety of pathological conditions like respiratory, cardiovascular and metabolic disorders. We have developed a non-invasive, portable, easy to use and economic respiratory sensor. It measures the temperature difference between inhalation and exhalation phases of respiratory cycle. The difference in temperature has been converted into a digital signal using 8 bit microcontroller (Atmega 328). By analyzing the digital signal, we can detect abnormalities like tachypnea, bradypnea and apnea. To track the unusual or sudden change in respiratory rate a buzzer system has been incorporated with the device. Graphical recordings corresponding to the calculated respiratory rate has been simultaneously obtained for the reference. This device can be used to detect sleeping disorder and abnormal respiration rate.**

I. Introduction

Among various medical health measurement parameters, respiration rate is a key indicator of the basic functionality of a body. The respiration rate is the number of breaths a person takes per minute. The normal respiration rate of an individual is $12-20$ breath/min. The rate is usually measured manually by counting the movement of the thoracic cavity per minute. Abnormal respiration rate can be categorized as Tachypnea (too high), Bradypnea (too low) or Apnea (absent).

Abnormal respiration rate is a key indicator of physiological disorders which requires an immediate attention. Respiration rate is the last core vital sign which determines the life of a patient and its continuous monitoring causes minimum inconvenience to the patient. There are number of methods available to measure respiration rate.

a) Manual method: It is the common method used for measuring the respiration rate. It is normally done by counting the number of exhalation per minute, or by observing the thoracic movements and listening to the breath sounds. However, manual methods are unreliable and prone to error.

b) Thoracic impedance: The thoracic chest wall expands and contracts during respiratory cycle. Respiration rate can be determined by measuring changes in electrical impedance associated with this movement.

c) Capnometers: It is a device which measures the carbon dioxide concentration in respiratory gases. A cannula is placed across the nasal airways and it continuously draws gas sample which is analysed by spectrography. Capnometry measurement of respiration rate is the most frequent technology used by anaesthesiologists. By this method the patients have to bear the cannula which is connected across the nasal region. However, in this method bearing a cannula across the nasal region susceptible to dislodging or clogging.

Pulse oximetry (which measures O_2 saturation in blood) is also used for monitoring the respiratory rate .

The research mainly focuses on the development of portable, and highly economical respiration monitoring system. Analog temperature sensor is the principle sensor of this device. It is a highly user friendly device which could be used both by a medical staff in a hospital or by the user at home since it does not require any skilled training. A small sensor is to be clipped onto the nose. The LCD attached to the device will display the respiration rate. If the rate goes above or below a particular threshold, an alarm will be triggered.

The paper is arranged in three main categories. First category explains the detailed block diagram and schematic of the device. Next category is followed by real time data collection by the device. The last category explains the analysis part performed on the data collected by the device.

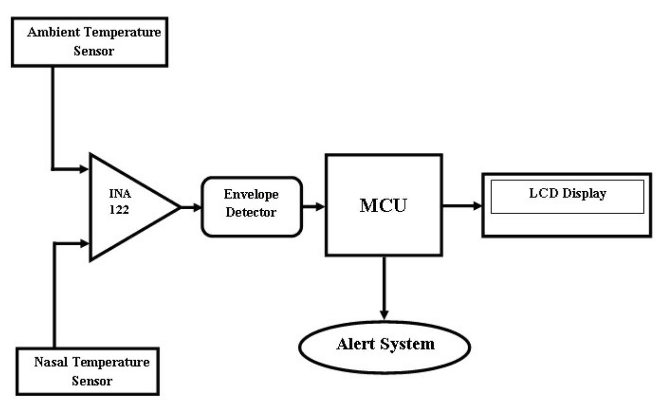

Fig. 1: Block Diagram of Respiratory Monitoring System.

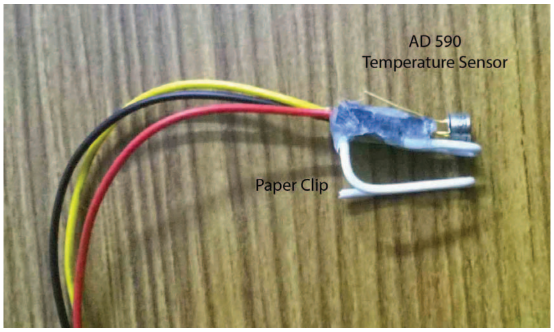

Fig. 2: Nasal Temperature sensor Mounting

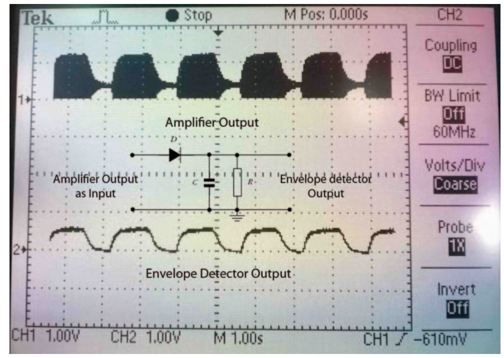

Fig. 3: Amplified output & Envelope detected output.

II. Previous Work

A thermistor has been used to monitor the respiration rate [1]. Respiratory monitoring system based on thoracic expansion used a belt mounted with a transducer to measure changes in the circumference of the chest or abdomen [2]. Another method utilized a capacitive sensor mounted on a shirt to determine respiratory patterns through chest expansion [3]. All these sensors were to be worn around the chest that causes inconvenience and discomfort to the user. In order to tackle such problems, some works have been done to indirectly measure the respiratory rate with sensors which make no contact with the nasal region. Another approach was to remotely monitor breathing rate in real-time using a high precision, single-point infrared sensor [4]. Another non-contact approach was the use of thermal imaging to recover the breathing waveform from the nostrils of the patient [5]. An involuntary monitoring method has been proposed to detect the breath rate and heart rate by using an under pillow pressure sensor which was composed of some fluid-filled incompressible polyvinyl tubes set in parallel and sandwiched between two acrylic plates [6].

III. System

We have developed an ultra low cost (approximately Rs700/-) microcontroller based respiration monitoring system. It has a probe which consist of an analog temperature sensor and that has to be placed at the tip of the nasal region. The probe can be clipped with the nostril. The respiration rate is displayed on a 16x2 LCD screen. If the respiration rate is beyond normal, a buzzer gets triggered. The system will generate an alarm if the respiration rate is not constant or if there is a sudden abnormal change. Fig 1 describes the block diagram of the system.

A. Block Diagram

Temperature Sensor: The system uses two analog temperature sensors AD590. One of these is used to measure the ambient temperature and the other one computes the temperature change near the nasal region (Fig 2). The rate of inhalation and exhalation affects the temperature near the nasal passage and ultimately varies the output of temperature sensor. The AD590 is an integrated-circuit temperature transducer which measures absolute temperature and provides an output current proportional to the temperature. The output current is converted to voltage for analog signal processing. The ambient temperature sensor produces a constant output during the time of inhalation and exhalation. The final output is obtained by comparing the voltage at the output of the nasal with the ambient temperature sensor. The presence of the ambient temperature sensor makes the device usable in all environmental conditions, as it becomes independent of environmental temperature.

Analog Signal Processing: The output of the two temperature sensors is fed into an instrument amplifier (INA122). The amplifier works in a differential mode. Instrumentation amplifier has a high gain, so it amplifies the very small temperature difference generated across the nasal region. Output of the amplifier is fed into the envelope detector. Fig: 3 shows the output of the amplifier and the envelope detector on a digital signal oscilloscope(DSO). The envelope detector converts the change in temperature during inhalation and exhalation into a pulse like signal. Then the envelope detector output is fed into ADC pin of a microcontroller for processing.

Microcontroller Atmega 328 which has 10 bit ADC is used to read the signal from the envelope detector. The program inside the microcontroller calculates the respiration rate and displays it on the screen. The controller can also be connected to a computer and the signal can be fed to a software (e.g. matlab) for post processing.

Display and Alarm: 16x2 alphanumeric LCD is used to display the respiration rate. It also displays warning if the rate crosses the threshold. A buzzer is connected to the microcontroller to generate an alarm for the patient and the medical staff.

B. Schematic Diagram

The schematic of the Respiratory monitoring system is shown in Fig. 6. The two temperature sensors convert the nasal temperature difference into voltage signal. Each crest of the signal is due to inspiration and each trough is due to expiration. This is done with the help of a precision instrumentation amplifier INA122. Its gain is set by the resistance value R connected across pin-1 and pin-8 (using the formula: $Gain = 5 + \frac{200k}{R}$). The gain is set to a large value so that it can amplify

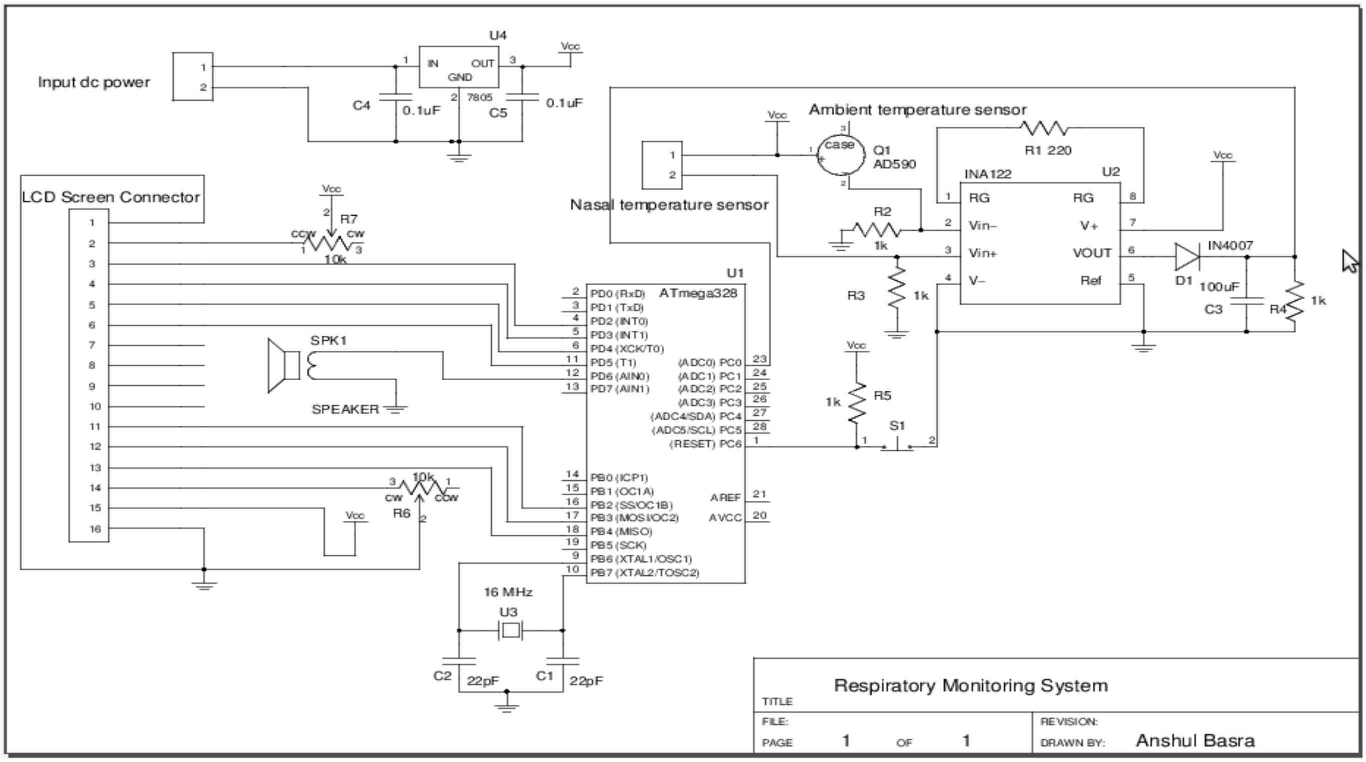

Fig. 6: Schematic of Respiratory Monitoring System.

small differential voltages. Nasal temperature sensor and ambient temperature sensor are connected to the non-inverting and inverting terminals of the amplifier respectively. The output is fed into the "Envelope Detector" circuit which comprises of a RC filter network of very small time constant(RC). The RC is made small to get the envelope of the generated noisy signal. It extracts the desired information from the signal. To follow the signal envelope, the magnitude of the slope of the RC discharge must be greater than the magnitude of the slope of the signal. $\frac{dv}{dt} >= slope\ of\ the\ input\ signal$(where v= voltage across capacitor). The detected output is then fed into the analog pin 0 of the microcontroller unit.

C. *Prototype of Respiratory Monitoring System.*

The prototype for the respiratory monitoring system is shown in Fig. 4 and Fig. 5. The 16x2 lcd in Fig. 5 displays the respiration rate.

IV. Results

All these observations were taken by clipping the nasal temperature probe across the nasal region. The results were divided into three segments. A set of results was collected by the MSO from the output of the amplifier and the envelope detector. Graphs on the Mixed signal oscilloscope (MSO) were studied and analysed. The other set of results were

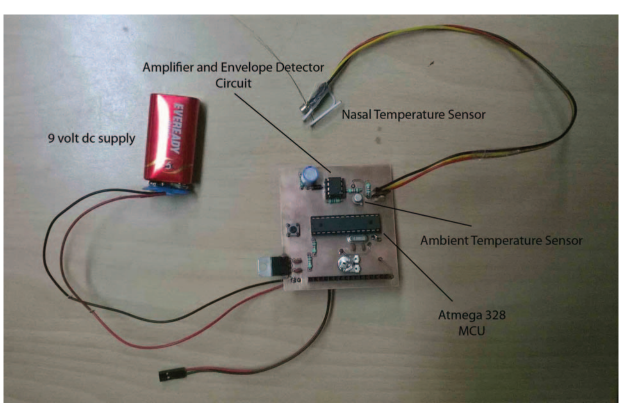

Fig. 4: PCB top assembly for the Respiratory Monitoring System.

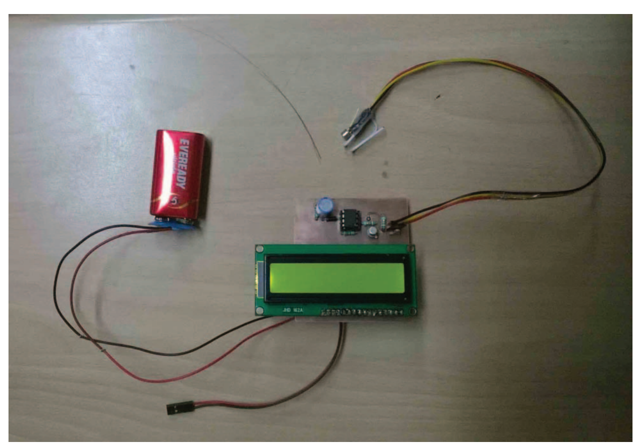

Fig. 5: Complete assembly of Respiratory Monitoring System.

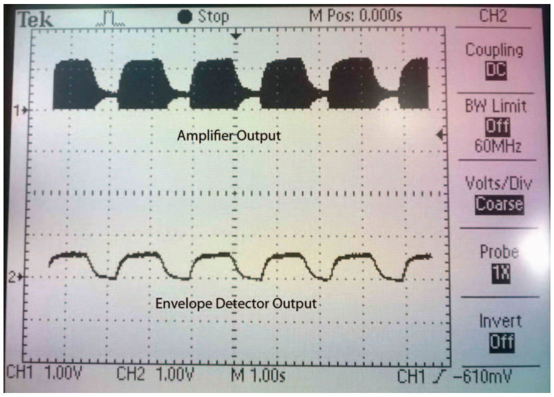

Fig. 7: Amplified & Envelope Detector output on DSO for a healthy volunteer with a normal breathing rate.

obtained by converting the analog signal at the output of the envelope detector into digital signal. Next the digital signal was transmitted to the matlab over the serial port. The data was analysed with the help of matlab. Finally analysis was done inside the controller in real time and the results were displayed on the LCD screen.

A. Observations of graphs on Mixed Signal Oscilloscope (MSO)

MSO was used to study and analyse the graphs obtained at the output of amplifier and the envelope detector. Fig. 7 shows the graph for a human being breathing normally. The envelope detector converts the signal into a pulse form by removing the high frequency noise. The crest in the graph is the time when the person is exhaling, and the trough in the graph is the time when the person is inhaling.

One suffering from **Tachypnea** has high respiration rate. The Fig.8 shows graphs with high breathing rate. If a person is doing exercise or is passing through huge stress, the respiration rate increases. The device can be set to give a warning alarm if the respiration rate crosses the threshold. It will alert the patient and it can also prevent the person from doing over exercise.

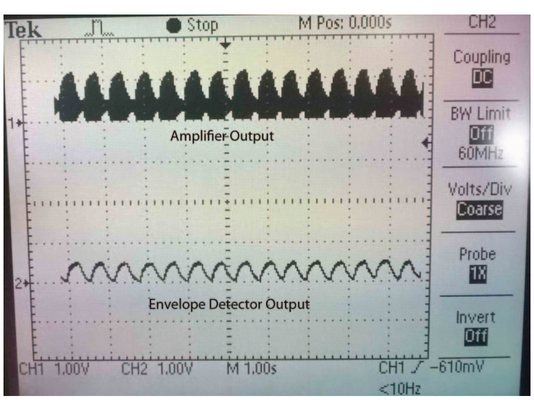

Fig. 8: Amplified output & Envelope Detector output for a Tachypnea patient.

Patient suffering from **Bradypnea** have low breath rate as shown in Fig.9. A healthy human being between 12 and 50 having respiration rate less than 12 is a patient of bradypnea. A patient suffering form bradypnea needs immediate attention and needs supply of oxygen. The device will generate an alarm in such a case.

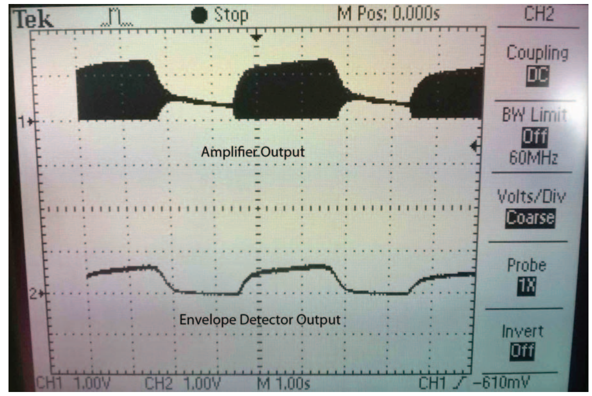

Fig. 9: Amplified output & Envelope Detector output for a Bradypnea patient.

The device can also be used to get a rough idea about the capacity of the lung. Fig. 10 and Fig.11 shows situations when the patient was continuously inhaling or exhaling. The time for which a person can continuously inhale or exhale can be calculated from the MSO. It gives an idea of the lung capacity of an individual.

B. Observations on MATLAB

The analog waveform across the envelope detector was converted to digital form by the microcontroller and then transmitted to the computer. Matlab was used to receive and store the digital data for post processing. Fig.12 shows the graph of the breathing rate of a healthy human being. Fast Fourier Transform is performed on the data. A sharp peak can be seen at .3892 Hz. Hence the respiration rate obtained using the software is **23 cycle per minute**. Fig. 13 shows the graph of a person breathing heavily. FFT of the graph

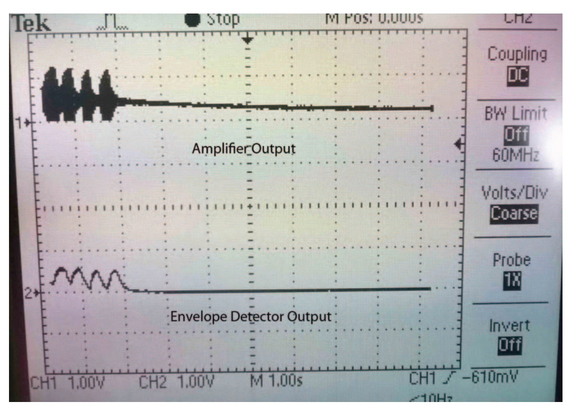

Fig. 10: Amplified output & Envelope Detector output for continuously inhaling.

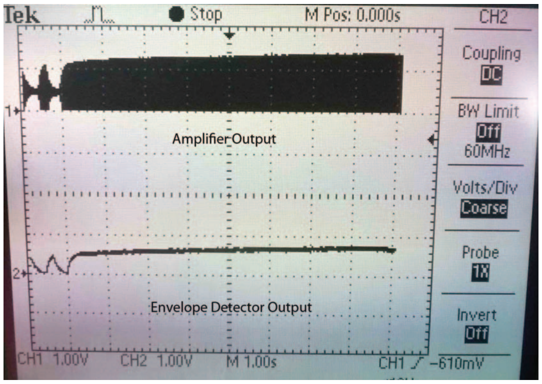

Fig. 11: Amplified output & Envelope Detector output for continuously exhaling.

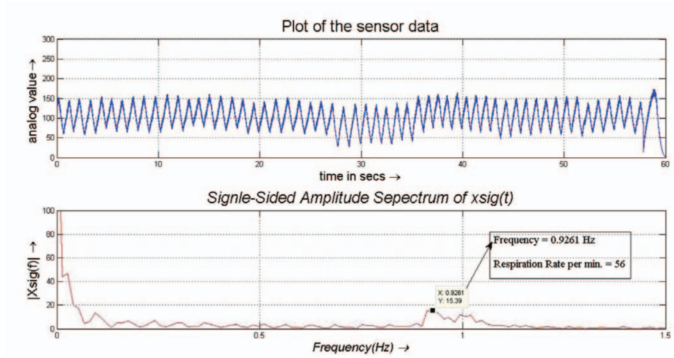

Fig. 13: Fast Fourier Transform of Fast Breathing.

generates a peak at a much higher frequency as compared to normal breathing. The peak is found at 0.9261 Hz. Hence the respiration rate obtained using software is **56 cycle per minute**. Similarly, under slow breathing condition as shown in Fig. 14 the frequency is the lowest at 0.1666 Hz. The respiration rate is **10 cycle per minute**.

Non-uniform breathing rate of a patient suffering from apnea or asthma can be identified through the device. We had taken data over a time span of 180 seconds, wherein every consecutive 60 seconds represent fast, normal and deep breathing rate. Fig. 15 shows a non uniform breathing rate graph. The red line in the graph is the mean of all the data. With the help of the mean value, the analog graph is converted into a varying pulse signal. If any point on the graph (Fig. 15a) is higher than the mean, it is considered as 1 in Fig. 15b, otherwise it is considered 0. Spectrogram analysis of Fig. 15b is shown in Fig. 15c. Spectrogram represents the frequency components of the signal with respect to time. If a FFT is performed, the time information is lost. So, to keep both the time and frequency information together, spectrogram is performed. The magnitude of the frequency component at a particular time can be studied from it. From Fig. 15c it can be seen that the reddish component of the graph decreases from left to right. The color bar shown in the right side of the graph shows the magnitude of the frequency corresponding to it. After 60 seconds some yellow coloured strips are visible and after 120 seconds some blue strips are visible. In this way, as we move to the right, the frequency of the graph decreases.

V. Future Work

The proposed respiration monitoring system has shown results which are promising and which enable us to figure out its future use. The system can be used for real time monitoring a patient suffering from various respiratory diseases. The system can be prototyped into a much more smaller package which can be operated wirelessly and much more patient-friendly. The device can be connected to a real time system to send the alert messages and other concerned data related to the health of a patient. It successfully measures the respiration rate and can be used to tackle sleep apnea, pulmonary fibrosis, aspiration pneumonia, chronic obstructive pulmonary disease and asthma. This device can work as a boon for the patients suffering from sleep apnea. In the case of sleep apnea, a patient may cease to breath while sleeping. In such case, this wearable device can gives feedback to the patient in the form of an alarm.

VI. Conclusion

This paper presents a novel technique for calculating the respiration rate by monitoring the change in the breathing temperature across the nasal region. The results obtained from our formal experiments are promising. Data from the test set clearly demonstrate that two AD590 temperature sensors

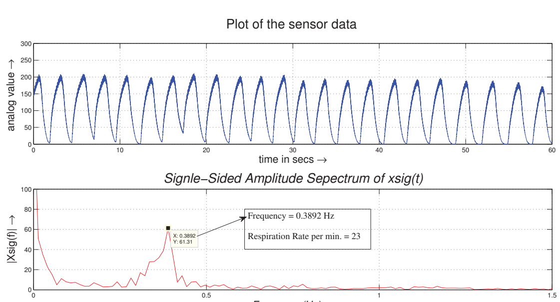

Fig. 12: Fast Fourier Transform of Normal Breathing.

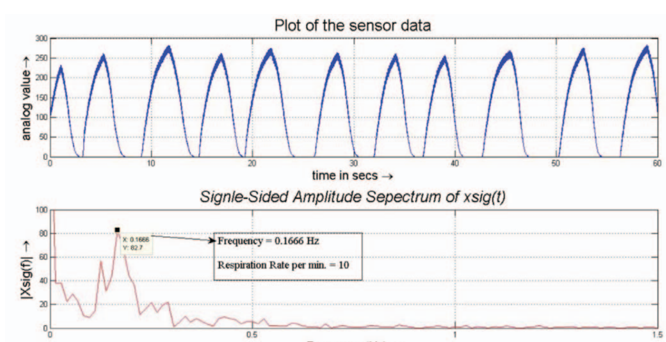

Fig. 14: Fast Fourier Transform of Deep Breathing.

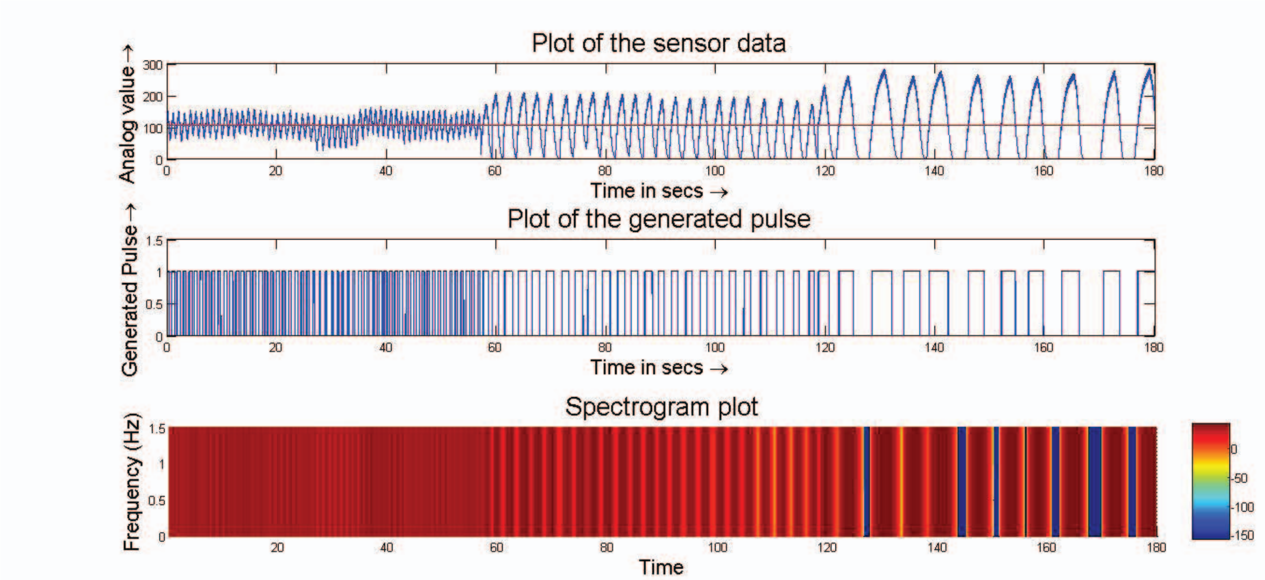

Fig. 15: a)Graph of a non uniform respiration rate. b)Conversion of graph into pulse form. c) Spectrogram of the non uniform respiration rate graph

combined with a good analog circuit can be used to detect subtle temperature changes corresponding to inhalation and exhalation. The device can also detect complex problem like non uniform breathing rate. The cost of the device is less than 700 rupees.

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