Techniques for APNOEA Detection

Utsav Dave
Undergraduate Student, D J Sanghvi College of Engineering
Plot U-15, JVPD Scheme,
Vile Parle (w), Mumbai-400056

Drashti Gandhi
Undergraduate Student, D J Sanghvi College of Engineering
Plot U-15, JVPD Scheme,
Vile Parle (w), Mumbai-400056

Mangal Dandekar
Assistant Professor, D J Sanghvi College of Engineering
Plot U-15, JVPD Scheme,
Vile Parle (w), Mumbai-400056

ABSTRACT
Sleep apnoea is the most common form of different types of sleep-related breathing disorders. It is characterized by repetitive stoppage of respiratory flow during sleep. This paper discusses an approach towards identifying the presence of sleep apnoea based on the acoustic signal of respiration. Different techniques for apnoea detection are discussed in this paper. The characterization of breathing sound can be carried by Voice Activity Detection (VAD) algorithm, which is used to measure the energy of the acoustic respiratory signal during breath and breathe hold. VAD is useful as a predictive tool for the segmentation of breath into speech and silence or non-sound segments. VAD based on zero crossing rate and short energy serves as a simple and fast method approach to divide the signal into voiced and unvoiced classes. Other methods using Capnostat and using strain gauge sensor are discussed. In both methods of Capnostat, we are measuring CO_2 in the breath by counting how many times CO_2 increases in the breath. Thus, we can determine respiration rate. In the first method, breath by breath samples are taken. Continuous monitoring of CO_2 is not possible in the first method, it is only possible in the second method.

Keywords
Apnoea, apnoea detection methods, Voice Activity Detection Algorithm (VAD), respiration monitoring, Zero crossing rate, voiced and un-voiced signals, capnostat, strain gauge sensing

1. INTRODUCTION
Sleep apnoea is the very common respiratory disorder during sleep, which is characterized by cessations or stoppage of airflow to the lungs. Apnoea is basically divided into two types: central and obstructive. Central apnoea is due to some deficiency in respiratory system development in neonates and obstructive apnoea is due to some obstruction in the airflow. The stoppage in breathing must last more than 10 seconds to be considered an apnoea event. Apnoea events can occur 5 to 30 times an hour. The most common and readily visible symptoms of sleep apnoea are snoring, nocturnal arousals, sweating and restless sleep. Moreover, like all sleeping disorders, symptoms of sleep apnoea do not occur just during the night. Some of the daytime symptoms are morning headaches, depression, impaired concentration and excessive sleepiness. [1, 2]In fact, sleep apnoea is associated with a major risk factor of health implications and increased cardiovascular disease which may even result in sudden death. It has been linked to irritability, depression, sexual dysfunction, high blood pressure (hypertension), learning and memory difficulties, in addition to stroke and heart attack. [1, 2,3]Several treatment options for sleep apnoea patients include weight loss, positional therapy, oral appliances, surgical procedures and continuous positive airway pressure (CPAP). CPAP is a common and effective treatment especially for patients with moderate to severe sleep apnoea. CPAP devices are masks worn during sleep that improves oxygen saturation and reduces sleep fragmentation.

2. VARIOUS TECHNIQUES FOR APNOEA DETECTION
Over the past few years of related research, emphasis and focus was primarily on presenting methods for the automatic processing of different statistical characteristics and features of different signals such as thorax and abdomen effort signals, tracheal sound, nasal air flow, oxygen saturation, electrical activity of the heart (ECG) and electrical activity of the brain (EEG) for the detection of sleep apnoea. [3]The sleep apnoea is generally caused by the blockage of the respiratory airway. This is characterized by iterativeepisodes of breathing cessation or stoppage. Thus the respiratory signal recording analysis during sleep becomes very valuable so as to estimate respiratory flow and distinguish the changes in the breathing pattern of the patient. To provide additional and complementary information, other biological signal data such as ECG, blood oxygen saturation, blood pressure, could be used to analyze sleep data as clinical experience indicates that an apneic event is frequently accompanied by a fall in the blood oxygen saturation. [4] By cyclic variations in the duration of a heartbeat (ECG)Apnoeic event is frequentlyaccomplished; this consists of bradycardia during apnoea followed by tachycardia upon its cessation. [5]

Recently based on tracheal breathing sound recording analysis during sleep, the study reports a new fully automatic technology for sleep apnoea detection.[6] The total energy of the tracheal sound segments within the sound and silence periods were found and then the data was clustered to classify as sound signals. The outcomes show high sensitivity and specificity values of more than 90% in differentiating normal respiration from disordered breathing in patients.Abdominal or chest respiratory movements can be sensed using a strain gauge sensor. Several studies for the non-invasive sensing of the respiration rate use mean absolute amplitude analysis of the thoracic and the abdominal signals showed that both signals are able to indicate the occurrence of sleep apnoea events. [7]Various portable monitor devices like sleepstrip, already exist in the market. It is a home sleep test diagnostic device. This device has to be worn for a minimum of five hours of sleep and the actual device is placed on the individual's face where the two flow sensors (oral and nasal thermistors) are placed just below the nose and above the upper lip to capture the breath of the patient. [8]

3. EFFECT OF RESPIRATORY ACTIVITY ON ECG AND BLOOD PRESSURE SIGNALS
Eithoven et al. in 1913, recognized the breathing related features in ECG and systematically analyzed the effects on EEG by respiratory movements. It is a well-known fact that respiratory action produces rotation of the cardiac vector;this produces a change in ECG. Heart rate fastens or accelerates during inspiration and slows down during expiration [9, 10]. The magnitude of the oscillation is variable and varies from individual to individual. Fig. 1 shows effect of respiratory activity on ECG.

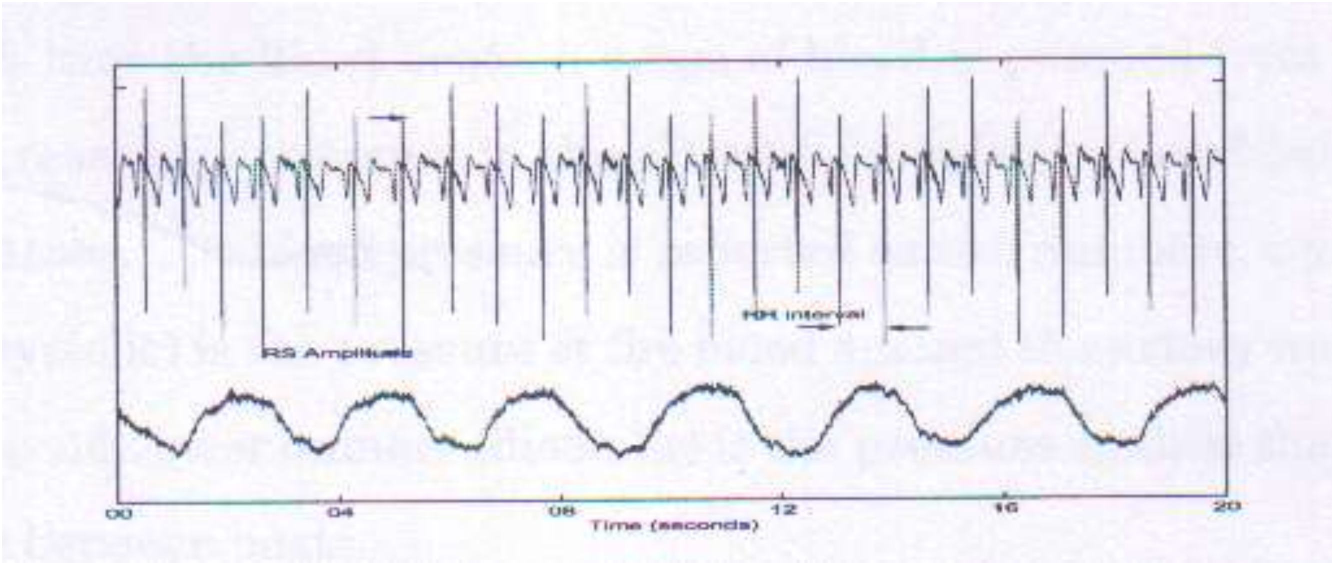

Fig 1: A reference respiration signal (lower trace), obtained from a nasal thermistor and an ECG (upper trace) The ECG amplitude can be seen to be modulated by respiration. [10]

During the inspiratory phase, the apex of the heart is stretched towards the abdomen because of the air-filled lungs, helped by the shifting down of the diaphragm. During expiration, the elevation of the diaphragm occurs, that further helps the emptying of the lungs, compresses the apex of the heart towards the breast. Thus changein the angle of electric cardiac vector takes place due to changes in respiration with a reference vector. These changes modulate the amplitude of the ECG signal. It is noted that the modulation of the QRS amplitude is particularly significant. Appropriate positioning of the ECG electrodes can maximize the inducedrespiration modulation; it is known that Lead II, shows greater modulation than Lead I. Figure 1 shows a section of ECG and a corresponding reference respiration signal obtained from a nasal thermistor. The ECG amplitude modulates with respiration as shown. By demodulating this signal, apnoea can be detected. Figure 2 shows inspiratory decrease in systolic blood pressure.

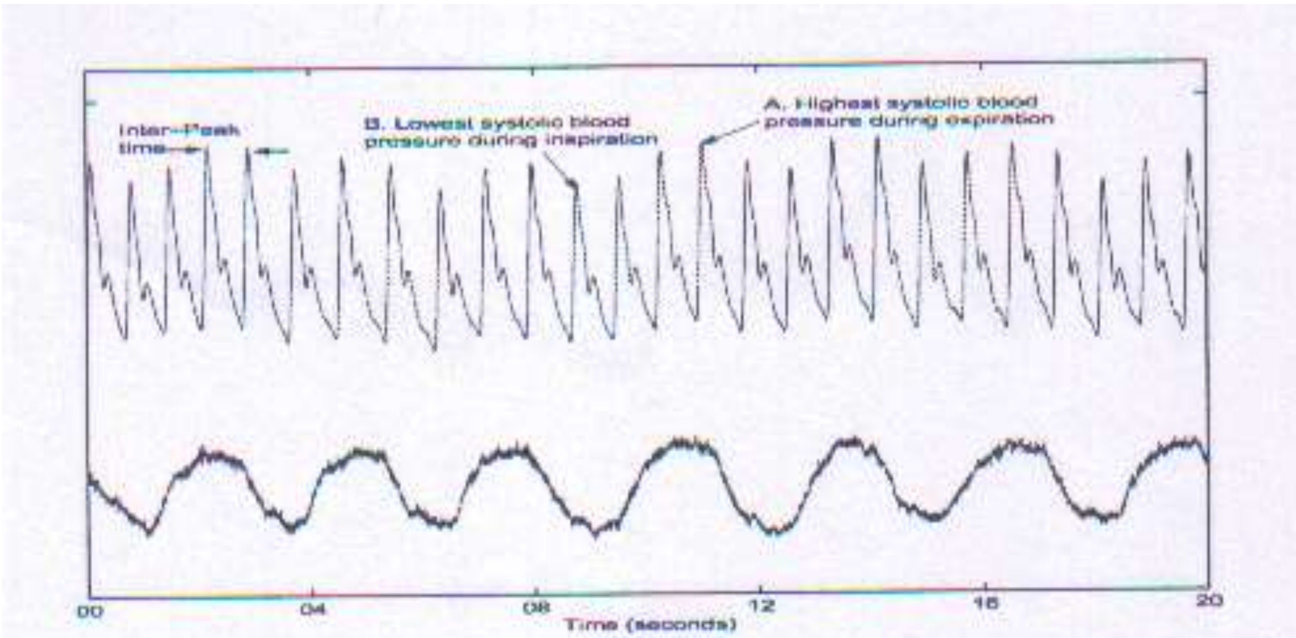

Fig 2: A reference respiration signal (lower trace), obtained from a nasal thermistor and a blood pressure signal (upper trace) [10]

4. VOICE ACTIVITY DETECTION (VAD)

Voice activity detector plays an important role in speech processing techniques such as speech coding, speech enhancement and speech recognition. A typical speech signal is shown in Figure 3.

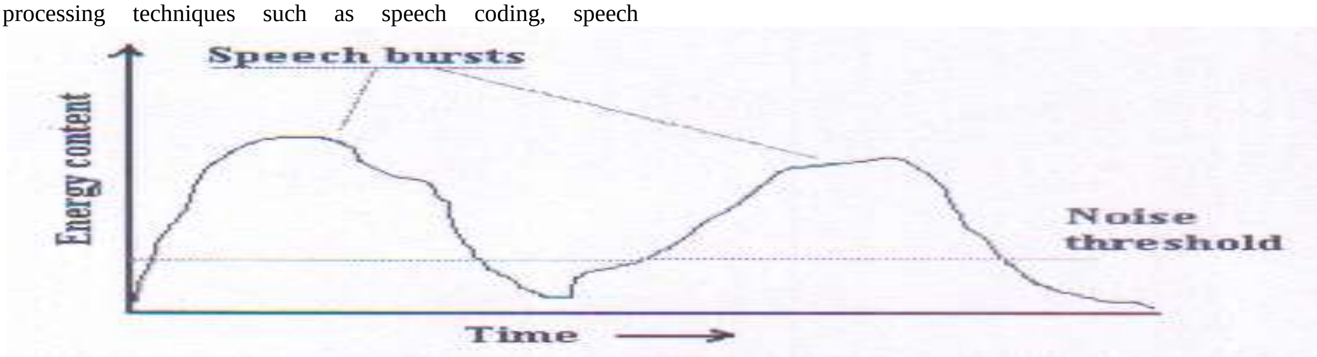

Fig3. A Typical Speech Signal [11]

Breathing sounds are detected with the help of a microphone below larynx and above suprasternal notch. [12] VAD relies on the measurement of features or sounds from speech which highly results in differentiating between voiced and unvoiced segments, where the regions of voice information within a given audio signal are referred to as 'voice active segments' and the pauses between talking are called 'silence' or 'voice inactive' segments. The term 'silence segment' does not refer to zero-energy packets but of incomprehensible sound or background noise. [12] VAD algorithms have to deal with silence periods with small audible content. Performance of VAD algorithm is higher when detection rate of active speech is maximized and false detection rate of inactive segments is minimized. Important and very widely used feature to separate different regions of audio signal is signal energy [3]. Figure 4 shows block diagram of VAD.

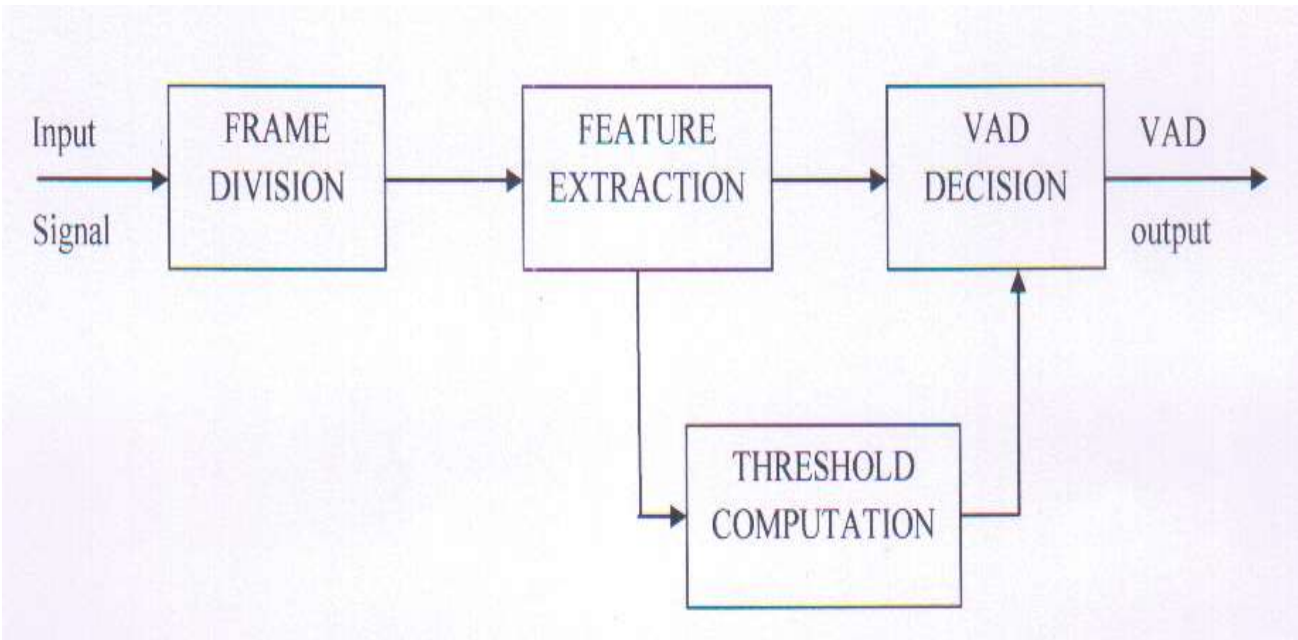

Fig4: Voice Activity Detection Method [13]

In the first step, the respiratory signal is filtered to remove the undesired frequency components. Most information about the breath sounds is within the range of 100-1400 Hz. VAD aims to differentiate voice and silence, where silence is mostly referring to background noise. A threshold value needs to be determined for comparing the signal value against noise. The energy of the signal is computed and VAD decision is made. [12].

4.1. Voice activity detection based on zero crossing rate (ZCR) and energy measure

Voice signals normally have high energy and low zero crossing rate while unvoiced signals have low energy and high zero crossing rate.

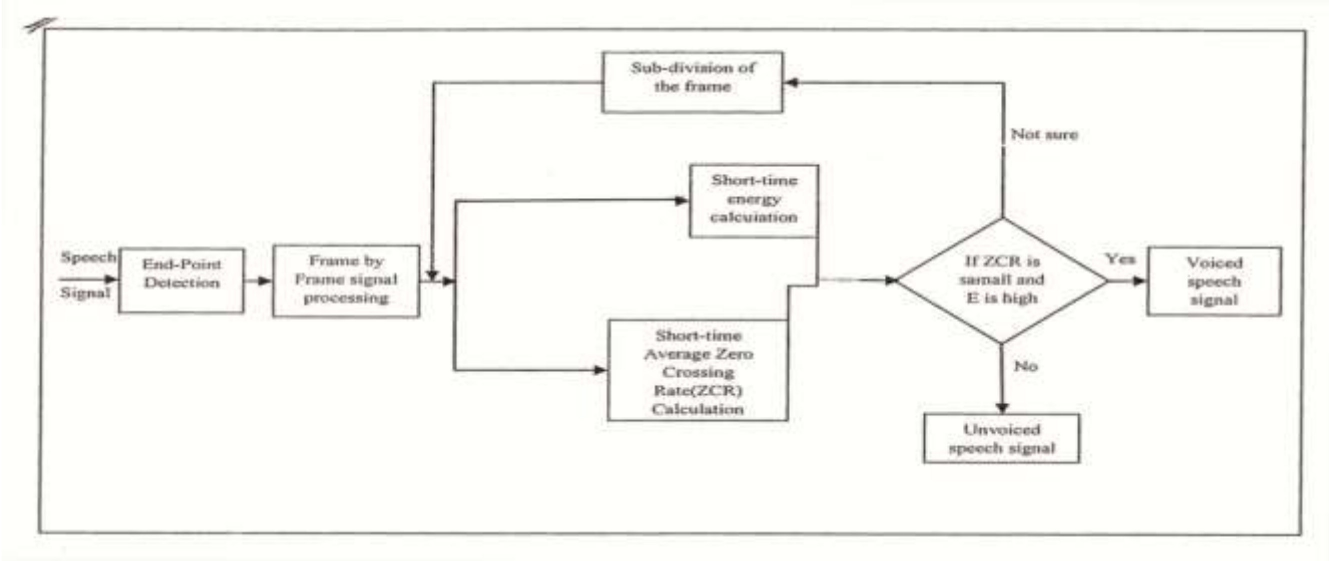

Fig5: Block diagram for VAD based on zero crossing rate and Energy measurements. [13]

The method begins with end point detection, in which the start and end points of the speech signal is evaluated. Following the end point detection a small frame of the signal is taken into account and the energy and zero crossing rate is calculated for the same. These calculations serves as a threshold for energy and zero crossing rate. In the frame by frame block, the speech signal is divided in 400 samples at 8 KHz sampling frequency which is equivalent to 50ms time duration. Short time energy and zero crossing rate measures of these rates are compared with the threshold values. If the values of the above parameters are more than the threshold values then the signal is considered to be a voice signal, else it is an unvoiced signal. Figure 5 shows VAD diagram based on ZCR (zero crossing rate) and energy measurements. If the decision is unclear or not predictable then the time frame is further reduced to 25ms (i.e. sub-divided into two sub-frames of 200 samples) and the parameters are estimated. This process is repeated until all the frames are classified into the two respective classes.

4.2. Classification of different errors in VAD

Measures to characterize different errors in VAD technique of speech detection are described below:

4.2.1 Front end clipping (FEC):

It is an error that misclassify the starting of speech as a non-speech signal.

4.2.2 Mid sentence clipping (MSC):

It is an error that classify mid-sentence of a speech as a non-speech signal.

4.2.3 Noise detection as speech (NDS):

In this type of error, noisy signal is classified as a speech signal

4.2.4 Overchange error (Over):

In this type of error, misclassification of the non-speech regions at the end of utterances as speech due to the implementation of hangover scheme.

4.2.5 Non-speech hit rate:

Percentage of correct declaration as non-speech signal

4.2.6 Speech hit rate:

Percentage of correct declaration as speech signal

4.2.7Average hit rate:

Average of speech and non-speech hit rate.

5. CAPNOSTAT:

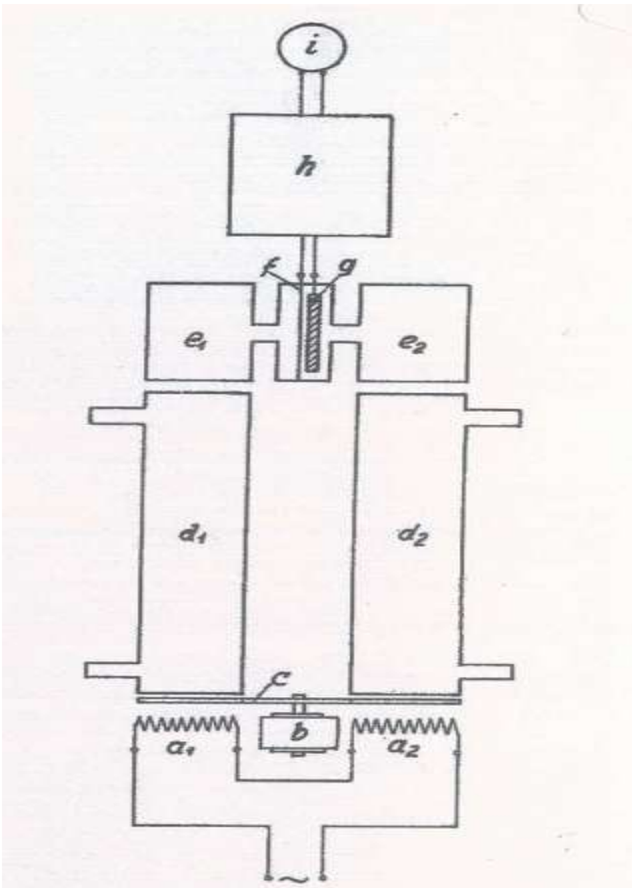

Fig 6 Capnostat (Luft Cell) [14]

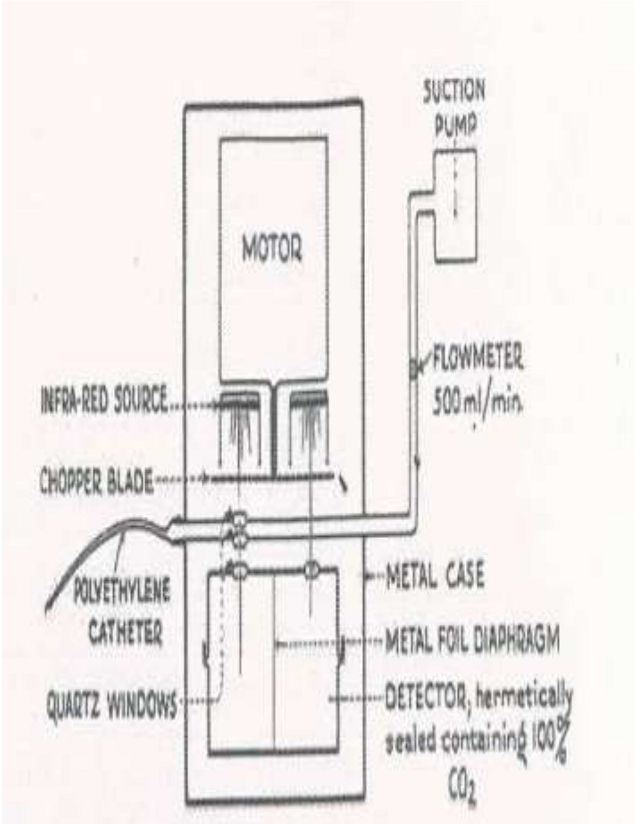

Fig 7 Capnostat (Continuous monitoring of respiration) [14]

In Fig 6, the radiations coming from sources a1 and a2 are interrupted by shutter wheel c, which is driven by motor b. These radiations then run through pipe d1 and d2, where d1 contains gas to be measured and d2 is the reference gas. These radiations then enter the reception layers e1 and e2. The reception chambers are separated by thin metal membranes f and g. If gas contains component to be measured, chamber e1 will receive weaker radiation as compared to e2, which leads to pressure difference between the chambers, which can be transformed in terms of change in capacitance. This change in capacitance is followed by an amplifier (h). The output is read out later by output device i.

Fig 7 shows a second case of CO_2 analyzer, which is the new method for apnoea detection. The sample is pumped through a polyethylene catheter. The detector is divided into two chambers which contains the reception layer which is equal in amount. The CO_2 absorbs specific portion of infrared spectrum, which will later heat up the chambers unequally in presence of CO_2, causing the displacement of diaphragm. The degree of displacement is electronically detected and recorded by a quartz window.

In both the cases, CO_2 in the breath is measured by counting how many times CO_2 increases in the breath. Thus, respiration rate is determined. In the first method, breath by breath samples are taken. Continuous monitoring of CO_2 is not possible in the first method, it is only possible in the second method.

6. APNOEA MONITORING USING STRAIN GAUGE

The block diagram mainly consists of an input amplifier circuit, motion and respiration channels, a motion/ respiration discrimination circuit and an alarm circuit. The input circuit consists of a high input impedance amplifier which couples the input signal from the sensor pad to the logic circuits. The sensor may be a strain gauge transducer embedded in the mattress. The output of the amplifier is adjusted to zero volts with offset adjustments provided in the amplifier. The amplifier signal goes to motion and respiration channels connected in parallel. The motion channel discriminates between motion and respiration as a function of frequency. In the case of motion signals, high level signals above a fixed threshold are detected from the sensor. In the respiration channel, a low pass filter is incorporated. Low frequency signals below 1.5Hz (respiration) cause the output of the Schmitt trigger circuit to pulse at the respiration rate. [15]

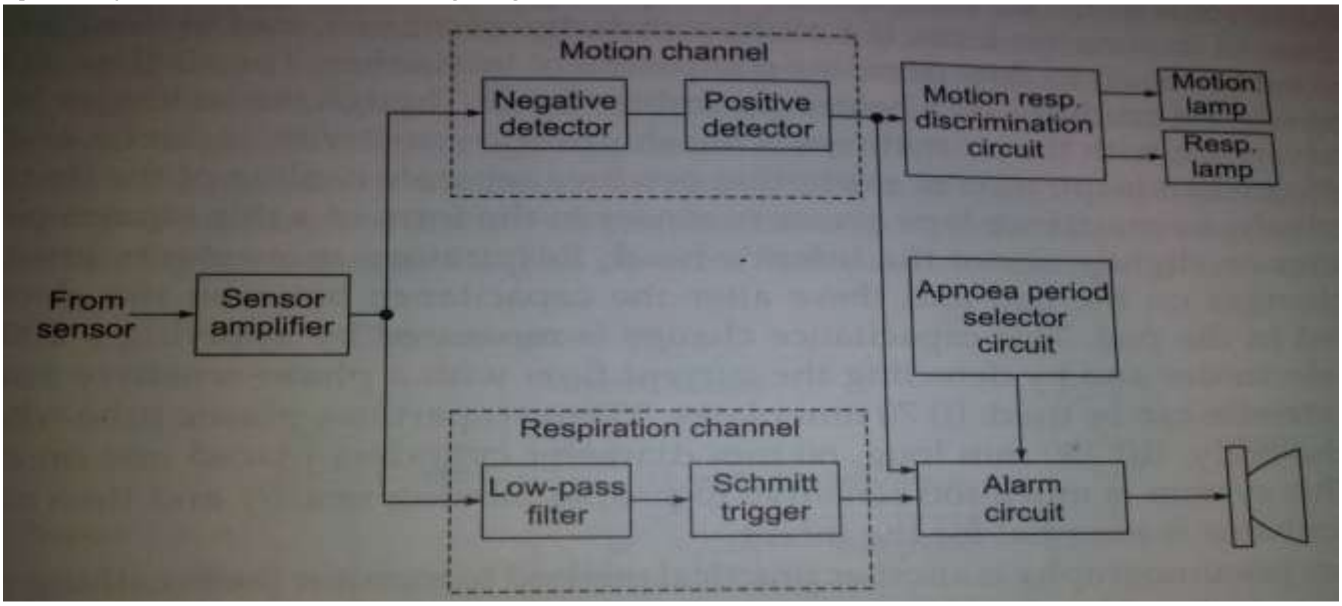

Fig8: Block diagram of apnoea monitor using strain gauge [15]

7. CONCLUSION

In this paper, various apnoea detection techniques with contact methods are discussed. Apnoea detection with the help of Voice Activity Detection (VAD) algorithm, using capnostat and using strain gauge sensor were discussed. Research works of several authors were analyzed. In acoustic method using VAD algorithm, snorting, speaking, crying, coughing by the patient showed negative effects in the results obtained. In both methods of Capnostat, we are measuring CO_2 in the breath by counting how many times CO_2 increases in the breath. Thus, we can determine respiration rate. In the first method, breath by breath samples are taken. Continuous monitoring of CO_2 is not possible in the first method, it is only possible in the second method. Apparatus used to collect exhaled CO_2 may face problems of displacement and the patient may not feel comfortable with the collecting apparatus. It may also affect the respiratory activity by increasing dead space. Subtle design changes in the collecting apparatus may cause large differences in the results obtained.In strain gauge sensor method, normally the inspiratory thoracic and abdominal expansion is almost synchronous. But if the upper airway is partially occluded, the movements may become asynchronous leading to erroneous results.To give better comfort and hygiene to patients and for accuracy of respiration rate measurement, a number of noncontact respiratory monitoring approaches were developed. In contact methods, there is a direct contact between the instrument and the patient's body. The distress caused by the contact device may alter the respiration rate. For long term monitoring of the patient, non-contact methods give improved patient comfort. Currently, non-contact methods are not used in a regular routine in clinical environments. But with more development, noncontact methods will effectively be used along with contact based respiration rate monitoring methods.

8. ACKNOWLEDGEMENTS
We would like to thank Prof. Mangal S Dandekar, Biomedical Department, D. J. Sanghvi College of Engineering for her guidance, contribution and support.

9. REFERENCES
[1] N. Israel, A. Tarasiuk, and Y. Zigel,Nocturnal Sound Analysis for the Diagnosis of Obstructive Sleep Apnea, in Proceedings of the 32nd IEEE International Conference on Engineering in Medicine and Biology Society (EMBS 2010), pp. 6146-6149, Sep. 2010.

[2] A. Yilmaz, and T. Dundar, "Home Recording for Pre-Phase Sleep Apnea Diagnosis by Holter Recorder Using MMC Memory", in Proceedings of the 2010 IEEE International Conference on Virtual Environments Human-Computer Interfaces and Measurement Systems (VECIMS), pp. 126-129, Sep. 2010.

[3] Laiali Almazaydeh, Khaled Elleithy, Miad Faezipour, Ahmad Abushakra, Apnoea detection based on respiratory signal classification, Procedia Computer Science 21 (2013) 310-316.

[4] M. Canosa, E. Hernandez, and V. Moret, Intelligent diagnosis of sleep apnoea syndrome, In IEEE Engineering in Medicine and Biology Magazine, vol 23, no.2, PP72-81, 2004.

[5] P. Chazal, T. Penzel, C. Heneghan, Automated detection of obstructive sleep apnoea at different time scales using the electrocardiogram, Institute of Physics Publishing, vol.25, No.4, pp 967-983, Aug 2004.

[6] A. Yadollahi, Z. Moussavi, Acoustic obstructive sleep apnoea detection in Proceedings of IEEE conference on Engineering in Medicine and Biology society (EMBC 2009) pp-7110-7113, Sep. 2009.

[7] A. Ng, J. Chung, M. Gohel et al., Evaluation of the performance of using mean absolute amplitude analysis of thoracic and abdominal signals for immediate indication of sleep apnoea events, Journal of clinical nursing, vol.17, no.17, pp 2360-2366, Sep 2008.

[8] T. Shochat, N. Hadas, M. Kerkhofs et. Al., The sleepstrip, an apnoea screener for the early detection of sleep apnoea syndrome, European respiratory Journal, Vol.19, pp121-126, 2002.

[9] M. Malik and A J Camm, editors. Heart rate variability. Futura publishing company, 1995.

[10] Laura Mason, Signal Processing Methods for Non-invasive respiration monitoring, A Technical Report, Trinity College, 2002.

[11] R Venkatesha Prasad, Abhijeet Sangwan et.al. Comparison of Voice Activity Detection Algorithm for VOIP, Proceedings of the seventh international symposium on computers and communication, 1530-46, 2002.

[12] Bryce Ensign Hill, Development of an acoustic respiratory monitor, A Technical Report, The University of Utah, Aug 2011.

[13] Sheshashyama Meduri, A survey and evaluation of voice activity detection algorithms, A Technical Report, Blekinge Tekniska Hogskola, June 2011.

[14] Michael B. Jaffe, Infrared Measurement of Carbon Dioxide in the Human Breath: "Breath – Through" Devices from Tyndall to the Present Day, Vol. 107, No. 3, September 2008.

[15] R. S. Khandpur, Handbook of Biomedical Instrumentation, 3rd edition, 2014.

.