A Review on Respiration Rate Estimation from ECG Signal

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***Abstract*— Respiration Rate is an important parameter for indication of normal and abnormal respiratory conditions. In general, Respiration rate is calculated when a person is in resting condition & it involves calculating the no. of times person chest rises per minute. Various types of instruments like Spirometer, Nasal thermistor; Plethysmography and Pneumotachometry are used to record the respiration signal. But it can't be used in all conditions like during exercise, sports activity and sleeping conditions because it increases patient discomfort. Therefore the methods of estimating respiratory information from various biomedical signals like Electrocardiogram (ECG) Signals, Blood Pressure (BP) and Photo-plethysmography (PPG) Signals are always demanded. Present study proposes various types of methods for extraction of breathing rate from ECG Signal during exercise. For that first acquire ECG Signal and then apply various algorithms for detection of Respiration rate from ECG Signal during Exercise.**

Keywords*— Respiration Rate, Spirometer, Nasal Thermistor, Pneumotachometry, Plethysmography, ECG, BP, PPG

I. Introduction

Human body consists of various types of biological systems. The main systems of the human body are cardiovascular system, Digestive system, Endocrine System, Exocrine system, Nervous system, renal system etc. Cardiac systems sometimes called circulatory system. Basically, human body is a complex integration of a number of physiological systems. These systems are dependent of one another and they are mutually correlated. Heart rate is affected by normal breathing due to coupling and interactions existing between cardiorespiratory systems. For that, signal processing methods can be used to derive information regarding heart rate and breathing rate from Electrocardiogram (ECG) Signal.

Respiration is defined as the movement of O2 from the outside air to the cells within tissues and expelling Co2 out. The volume of air inspired/breath is 500ml and during resting condition is about 5–8 liters of air/minute [1]. Respiratory rate is most important vital parameter. It gives indication about person's respiratory illness. Person breathing rate can be determined by counting the number of times the chest rises or falls per minute. Table I shows ranges of breathing rate. Breathing Rate varies with age, gender, weight and overall health. Breathing Rate increases during Exercise, Chronic pulmonary disease, fever and asthma. It decreases with the use of alcohol, abnormal metabolic conditions and apnoea. Various methods are used for measurement of respiratory rate like Spirometer, Thermistor method, Plethysmography and pneumotachometry. But these types of devices increases patient discomfort during exercise and sleeping conditions. Hence ECG Derived Respiration (EDR) is a good solution to derive respiratory information. Fig 1.Shows that normal breathing pattern.

TABLE I
NORMAL RANGES OF BREATHING RATES [1]

AGE	Respiratory Rate (Breath Per Minute)
New born	30-60
Infant (1 to 12 months)	30-60
Pre-schooler (3-5 years)	22-34
School-age child (6-12 years)	18-30
Adolescent (13-17 years)	12-16
Adult	12-18

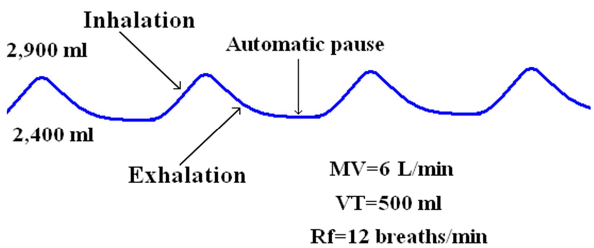

Fig. 1 Normal Respiratory Pattern [1]

II. Methods

Various methods are used for estimation of breathing rate from ECG Signal are as follows:

A. ECG Derived Respiration Signal by Discrete Wavelet Transform Method

Based on the paper [2] Respiration signals can be derived from ECG using Discrete Wavelet Transform. The Discrete wavelet transform decomposition method consists of low pass filters and high pass filters that divide total signal into two components is shown in Fig 2. In Discrete wavelet transforms, a LPF and a HPF that decompose the signal into two different scales. LPF Coefficients are referred to as “approximations” and HPF Coefficients are referred to as “details”. In this method, ECG Signal is decomposed up to 9^{th} level & reconstructs the detail (high frequency) component of 9^{th} decomposition. So, we get Respiratory Signal. The frequency range of detail (high frequency) signal up to 9th decomposition corresponds to the frequency range of 0.2 –0.4 Hz & respiration signal is present in this range. In this method, “Daubechies 6th order” wavelet is used because it gives better result.

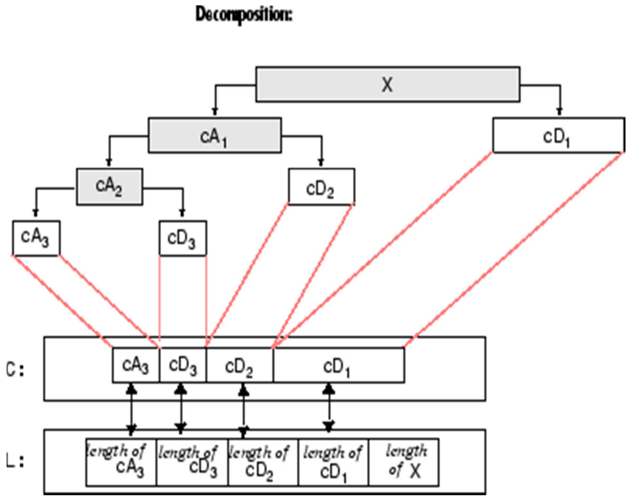

Fig. 2 Wavelet Decomposition Tree [3]

B. ECG Derived Respiration Signal by Empirical Mode Decomposition Method

Empirical Mode Decomposition (EMD) method is given by Huang et al [4]. This method is basically applied for non-stationary & non-linear signals such as biomedical signals.

EMD method decomposes signal into a collection of AM-FM Components or various oscillation modes. It also decomposes signal into a sum of various Intrinsic Mode Functions. Intrinsic Mode Function is a function which fulfils following criteria:

1) In total data length, the amount of smallest or largest value points must be equal with Zero-crossing points or differ by one and

2) Average value of envelop is defined by local maxima & local minima must be zero.

Steps of EMD algorithm can be summarized as follows [5]:

1. Take the data set x(t).
2. Find the locations of all maxima and minima of x(t);
3. Generate the upper envelop and lower envelope (eu(t), el(t)) by connecting the maxima and minima points separately with cubic spline interpolation;
4. compute the local mean r(t) = (eu (t)+el(t))/2;
5. Let d1(t) = x(t) − r(t). If d1(t) is a zero-mean function, then the iteration stops and d1 (t) is accepted as first IMF, i.e.,h1 (t) = *d*1 (*t*).
6. If not, use d1 (t) as the new data and repeat steps 1-4 until ending up with an IMF.

Once the first Intrinsic Mode Function h1 (t) is obtained, remaining IMF’s are obtained by applying shifting process to the low frequency (Residual) signal. Residual signal r1 (t) can be defined as

r1 (t) = x (t)-h1 (t)

Residual signal consists information regarding low frequency components. Shifting process will be continued until the final residue is a constant. At the end of decomposition process, noisy signal x (t) can be represented as a sum of high frequency components means IMF’s plus low frequency component means residue signal.

$$x(t) = \frac{1}{n}\sum_{i=1}^{n} h_i(t) + r_n(t)$$

C. ECG Derived Respiration Signal by EEMD Method

Disadvantage of EMD method is mode mixing problem. i.e. EMD cannot identify Intrinsic Mode Functions whose frequencies which are very close to each other. To overcome these difficulties, EEMD (Ensemble Empirical Mode Decomposition) algorithm is used to derive respiratory rate from the ECG signal.

Ensemble Empirical Mode Decomposition (EEMD) is a method which produces Intrinsic Mode Function which having average of signal plus white noise. In this method, white noise is added to the original noisy signal. [1] When EEMD is applied on ECG Signal then noisier signal is produced. By adding white noise, EEMD method eliminates mode mixing problem. Steps followed by authors for ECG derived using EEMD algorithm are as below:

1. Take original signal x(t).
2. Add white noise to original signal x(t).
3. If signal does not satisfy conditions of intrinsic mode functions then repeat above steps 1 and 2.
4. Obtain the magnitude response for every intrinsic mode function.
5. Find Intrinsic Mode Function which falls in frequency range of 0.2-0.4 Hz which is respiratory signal frequency range.

D. ECG Derived Respiration Signal by 4^{th} Order Central Moment

Based on paper [6], 4^{th} order central moment is used for estimation of respiration Signal for those patients who are examining a MRI tool as a diagnostic purpose. This slope based method is chosen because R peak of the ECG and slope of the QRS complex means (QR-slope & RS-slope) are changed in amplitude inside the MR-Scanner. The n^{th} order central moment is calculated for measure of the transient slope. 4^{th} order central moment which can be defined in a discrete way as follows [7]:

$$m_4 = \frac{1}{n}\sum_{i=1}^{n} (x(i) - \bar{x})^4$$

Steps followed by authors for ECG derived respiration using 4th order central moment are as below: [7]

1. Take original ECG signal x (t).
2. Denoised ECG Signal using a 45 HZ 5th order Butterworth low pass filter and 0.5 HZ 4th order Butterworth high pass filter
3. Calculate 4th order central moment and
4. Apply cubic spline interpolation for the detection of respiratory waveform.

Fig. 3 shows that different step for estimation of Respiratory Signal using 4th order central moment.

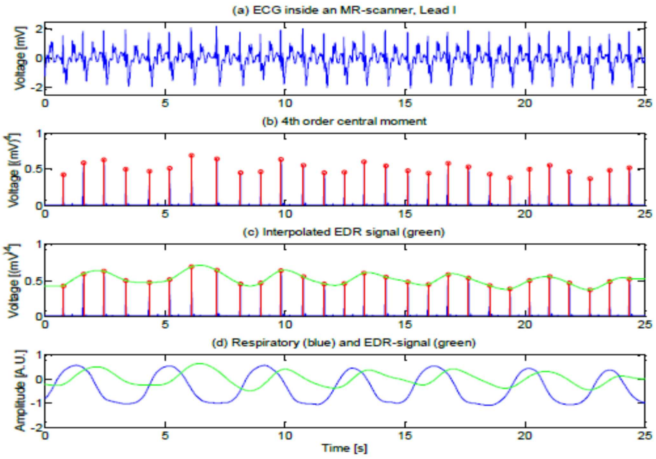

Fig. 3 Steps for estimating EDR Signal based on 4th order central moment [6]

E. *ECG Derived Respiration Signal by Homomorphic Filtering*

Based on paper [8], a new technique Homomorphic Filtering is used for the detection of respiratory signal from the ECG signal. In this method, two transform DFT & DCT are used. After that, compare the performance of EDR signal using Homomorphic filtering with the actual respiratory signal in terms of correlation coefficient, accuracy of respiratory rate & magnitude squared coherence coefficient. Comparison showed that in fig 4. Homomorphic filtering using discrete fourier transform is better than Discrete cosine transform.

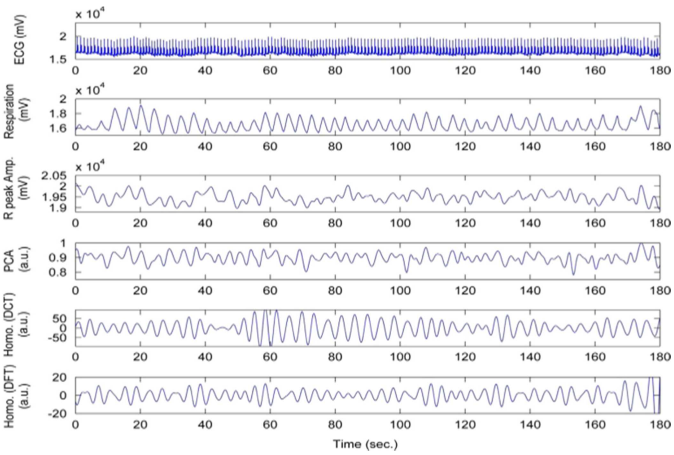

Fig. 4 ECG derive respiration signals : (a) Original Electrocardiogram signal (b) Actual respiratory signal (c) ECG derived respiration using Principal Component Analysis (d) ECG derived respiration using DCT & (e) ECG derived respiration using DFT. [8]

III. CONCLUSIONS

Several algorithms have been proposed in this literature for the ECG-derived respiratory signals. First DWT method provides less accuracy up to 80% because this method is not enough better to retrieve the original shape of respiratory signal.

Second EMD algorithm provides better performance compared to DWT method. Disadvantage of EMD method is if noisy (stress) ECG is used, then its amplitude-frequency components are overlap to each other.

Third EEMD method is an extension of EMD method. Advantage of EEMD method is to solve problem occur in EMD method (mode mixing).

Fourth method is EDR signal using 4th order central moment method, is basically used for cardiorespiratory disorder related patients because in these patients, RR interval is changed during respiration. Basically advantage of this method is to find QR-slope & RS-slope which is changed during respiration.

Last technique is homomorphic filtering technique which is applied on signal as well as image. The main aim behind this method is that the ECG signal is convolved with the transfer function of Linear Time Invariant system and it is influenced by the Respiratory process. Advantage of this method is to remove multiplicative (speckle) noise present in original signal.

FUTURE WORK

Future work will involve respiration signal derive from ECG signal based on R peak during Exercise. After that we can apply spline interpolation on R peak of ECG for detection of respiratory waveform.

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