A Comparative approach: Estimation of Respiration rate from ECG Signal during stress testing

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Abstract- Monitoring of Respiration activity is very important in diagnosis, therapeutics, during surgical procedures, Stress testing, monitoring sleeping disorders and cardiac & pulmonary related disorders. The joint study of respiratory and cardiac activity suggests indirect methods to derive the respiratory signal by electrocardiogram (ECG) processing. Extraction of respiratory activity from electrocardiogram (ECG) signal will eliminate the use of an additional hardware used to record respiration. The present study proposes various algorithms to estimate respiratory rate and Heart rate from ECG signal during incremental stage of exercise. For that, instrument like Treadmill test (TMT) with Bruce protocol is preferable. In this paper, five methods have been implemented, which are: (1) Discrete wavelet transform (DWT) method (2) Filtering concept method (3) R peak amplitude variation method (4) Homomorphic filter and (5) Neural network method. Comparison of result found that all methods have acceptable accuracy but EDR using neural network method gives highest accuracy compared to other methods.

Key Words: Respiration Rate, Treadmill test (TMT), Heart Rate, Bruce Protocol.

1. INTRODUCTION

The respiratory rate is defined as the number of breaths taken by a person per minute and is measured while the subject is at rest. [1] An accurate recording of the respiratory rate is important in predicting some serious medical events. Various direct methods can be used to measure respiration activity but they have certain drawbacks during stress testing, sports activity and when patients are suffering from various diseases. So, cardiopulmonary exercise testing (CPET) has become an important clinical tool to evaluate performance parameter of cardiovascular and pulmonary system. CPET is also used for measuring physical fitness of sports persons. For Treadmill exercise, Bruce protocol is used because it is the most commonly used protocol for exercise. Major problem during treadmill test is motion artifacts in signal acquisition and also discomfort during recording of respiratory parameters.

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. Figure 1 shows that normal respiratory pattern.

![Respiratory Pattern](image1)

Table 1: Normal Ranges of Breathing Rates [1]

<table>
<thead>
<tr>
<th>AGE</th>
<th>Respiratory Rate (Breath Per Minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New born</td>
<td>30-60</td>
</tr>
<tr>
<td>Infant (1 to 12 months)</td>
<td>30-60</td>
</tr>
<tr>
<td>Pre-schooler (3-5 years)</td>
<td>22-34</td>
</tr>
<tr>
<td>School-age child (6-12 years)</td>
<td>18-30</td>
</tr>
<tr>
<td>Adolescent (13-17 years)</td>
<td>12-16</td>
</tr>
<tr>
<td>Adult</td>
<td>12-18</td>
</tr>
</tbody>
</table>

Fig 1: Normal Respiratory Pattern [1]

2. MATERIALS AND METHOD

A. Subjects
For this study, fifteen healthy and non-smoker subjects aged 18 to 45 years were recruited. All subjects are considered as normal means they are not suffer from any cardiac and respiratory disorders.

B. Reference Respiratory Signal acquisition using Thermistor
Actual respiration signal is measured using NI- Vernier temperature sensor (thermistor) is fitted into oxygen mask. By using elastic straps, oxygen mask is strapped to the face of the subject which is shown in figure 2. The subject is able to breathe freely from nose and also through mouth, while there is an airtight seal between the face of the subject and mask.
C. ECG Derived Respiration Signal Methods

Respiratory signals are estimated from ECG using various methods: (i) Discrete wavelet transform (DWT) method (ii) Filtering concept (iii) R peak amplitude variation method (iv) Homomorphic Filter and (v) Neural network method.

1. EDR using Discrete wavelet transform Method

Respiration signal is derived from ECG using DWT method. During Treadmill exercise, ECG and respiration signals are recorded up to 9 minutes according to Bruce protocol. Next, apply DWT method on ECG signal in which signal is decomposed up to 10th level and then reconstructing details components for obtaining respiratory waveform.

2. EDR using Filtering Concept Method

Respiration signal is derived from ECG using Filtering concept method. Flow Diagram of EDR using filtering method is shown in below figure 4.

- During treadmill exercise, ECG signal using clamp electrodes and actual respiration signal is acquired.
- After that apply Moving average filter for removal of noises present in ECG for denoising.
- For estimation of respiration signal from ECG, apply bandpass filter of 0.1-0.3 Hz because respiratory signal is present in below 1 Hz.
- Next, apply rectification on estimated respiratory signal as well as actual respiratory signal for peak detection.
- Calculate estimated respiration rate (ERR) based on peak.
- Compare actual vs. estimated respiration rate.
3. EDR using R Peak amplitude variation Method

In this method, EDR signal is obtained through interpolation of R peak of ECG. Figure 6 shows that block diagram of EDR using R peak amplitude variation method.

![Block Diagram of EDR using R peak amplitude variation Method](image)

**Fig-6: Block Diagram of EDR using R peak amplitude variation Method**

a. ECG Signal and Respiration signal acquisition

During treadmill exercise, Respiration signal is recorded using thermistor and ECG signal is acquired using three clamp electrodes in which electrode is placed on subject’s right arm, left arm and wrist of the right arm as an reference.

b. Apply Bandpass Filter

ECG signal is passing through a bandpass filter to reduce the effect of muscle noise, power line interference noise, base line wander noise, and T-wave interference. The desirable pass band frequency is 5-15 Hz.

c. Differentiation

After filtering, the signal is differentiated to provide the slope information related to QRS complex.

d. Squaring Function

The squaring function makes the result positive and emphasizes large differences resulting from QRS complexes; the small differences arising from P and T waves are suppressed. The high-frequency components in the signal related to the QRS complex are further enhanced.

e. Moving Window Integrator

After squaring function, signal is allowed to pass through a moving window integrator to obtain wave-form feature information. The integration waveform will merge the QRS and T complexes together, if the window is too wide, and if it is too narrow then QRS complexes will generate many peaks in the integration waveform. The size of the window is chosen N=30.

f. Computation of Peak amplitude and location value

Next, peak detection algorithm is applied for computing maximum value (Peaks) and minimum position value (location). Then convert into discrete form for detection of R peak of ECG.

g. Interpolate R peak of ECG

Next, apply linear interpolation for connecting all R peak. At this stage, estimated respiratory signal is obtained.

h. Comparison of actual respiration rate vs. estimated rate

Calculate estimated respiration rate based on peak and compare it with actual respiration rate which is measured from thermistor.

![Implementation of EDR using R peak amplitude variation Method](image)

**Fig-7: Implementation of EDR using R peak amplitude variation Method**

4. EDR using Homomorphic Filtering Method

In many signal processing applications, Homomorphic filter is basically used to remove multiplicative noises present in the signal and also used to separate two signals that have been combined through convolution operation. [7]

Figure 8 shows that block diagram of EDR using Homomorphic filtering method.
The main concept used in this method is to transform convolved components of signal into additive form. Next, Bandpass filter is used to remove undesired components present in the signal. After that, apply inverse homomorphic de-convolution operation is applied to retain the respiratory information.

- Let assume an ECG signal as a $s(n)$ which is generated through convolution of two components: $s_1(n)$ and $s_2(n)$. Signal is transformed in the frequency domain using Fourier transform where convolution operation becomes multiplication and then logarithmic function is applied which is followed by the inverse Fourier transform (IFFT). These steps are used to transform multiplicative components of signal into additive form.

- Next, apply bandpass filter of 0.1-0.3 Hz for removal of undesired components present in signal.

- After filtering, inverse homomorphic de-convolution is applied for obtaining required respiratory components from the input ECG signal. The signal obtained at the output is carried out by first applying FFT to the signal and then exponential operation is performed which is followed by the IFFT. This operation provides required respiration signal at the output.

5. EDR using Neural network Method

Respiration signal is obtained from ECG signal using neural network method. Neural network is an efficient and powerful technique for prediction of respiratory signal. Neural networks have ability to train parameters and change their structure to satisfy the requirements.
3. RESULTS

Table shows that comparison of five EDR techniques with the actual respiration, the absolute error and accuracy for all are calculated and displayed in the table. It shows the correlation results between the extracted respiratory signal from ECG using five methods and the acquired respiratory signal for different subjects during 1st to 3rd stage of treadmill exercise.

Table 2: Result analysis of actual and estimated respiration rate during 1st stage of exercise

Table 3: Result analysis of actual and estimated respiration rate during 2nd stage of exercise
Table 4: Result analysis of actual and estimated respiration rate during 3rd stage of exercise

Note:
1. ARR: Actual Respiration Rate
2. ERR: Estimated Respiration Rate
3. M-I: ECG Derived Respiration Signal using Discrete Wavelet Transform
4. M-II: ECG Derived Respiration Signal using Filtering Concept
5. M-III: ECG Derived Respiration Signal using R peak amplitude variation Method
6. M-IV: ECG Derived Respiration Signal using Homomorphic Filter Method and
7. M-V: ECG Derived Respiration Signal using Neural network Method

Result shows that when stage is increased, absolute error is increased because quality of ECG is degraded in later stage compared to initial stage of exercise. During third stage, highest error is observed, but EDR using neural network method provides better performance compared to other methods.

In order to compare the estimated respiratory signal with the actual respiratory signal, the correlation coefficient is calculated. Correlation coefficient (r) is a measure that determines the degree to which two variable movements are associated. The range of values for the correlation coefficient is -1.0 to 1.0.

There are two types of correlation coefficient: 1. Positive correlation coefficient and 2. Negative correlation coefficient. If ERR is increasing with the increase of ARR, then correlation coefficient should be positive. The mathematical formula for calculating correlation coefficient (r) as follows:

$$r = \frac{n \sum(xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x)^2 - (\sum x)^2][n(\sum y)^2 - (\sum y)^2]}}$$

Where x and y represents the ARR and ERR data points, respectively and n is the length of data points. Correlation coefficient calculated for all the methods and is displayed in table.

Figure 12- (a), (b) and (c) shows that correlation coefficient between actual and estimated respiration rate using neural network method. During 1st stage, neural network method gives correlation coefficient upto 0.9920 (excellent relation) between ARR & ERR. During 2nd stage and 3rd stage of treadmill exercise, neural network method gives correlation coefficient upto 0.8376 (Strong relation) and 0.5981 (moderate relation) respectively.

Result shows that EDR using neural network method gives excellent performance during 1st stage. During incremental stage of exercise, relation between two variables is decreased; still it gives an acceptable result compared to other methods.
4. CONCLUSIONS

This paper presents five methods for prediction of Heart rate (HR) and Respiration rate (RR) during incremental stage of treadmill exercise. A preferred technique for deriving respiration signal from ECG is based on neural network because neural network is an efficient and powerful technique for prediction of respiratory signal. Neural networks have ability to train parameters and change their structure to satisfy the requirements. From results, it is proved that EDR using neural network has less absolute error compared to another methods. EDR methods were analyzed by statistical analysis of two different parameters and by taking into exercise condition for measurement of those parameters.

REFERENCES


