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

Vishakha Khambhati[1]
Department of Biomedical Engineering
Government Engineering College, Gandhinagar
Gujarat, India

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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.

Table-1
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

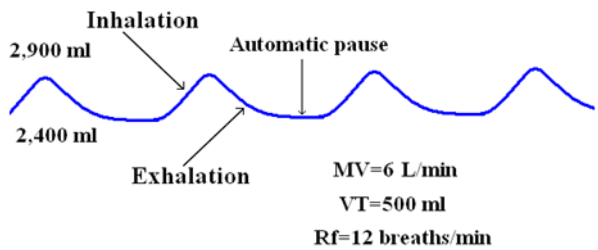

Fig-1: Normal Respiratory Pattern [1]

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.

Fig-2: Acquisition of Reference respiration signal using thermistor

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 upto 9 minute according to Bruce protocol. Next, apply DWT method on ECG signal in which signal is decomposed upto 10th level and then reconstructing details components for obtaining respiratory waveform.

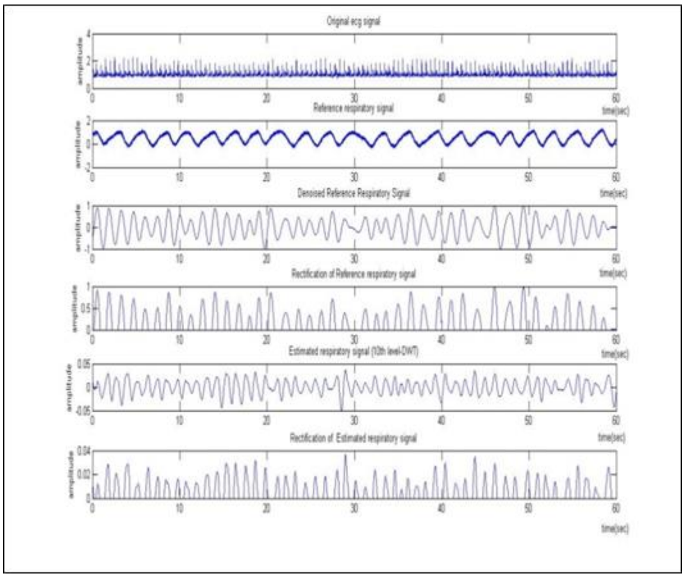

Fig-3: Implementation of EDR using DWT Method

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.

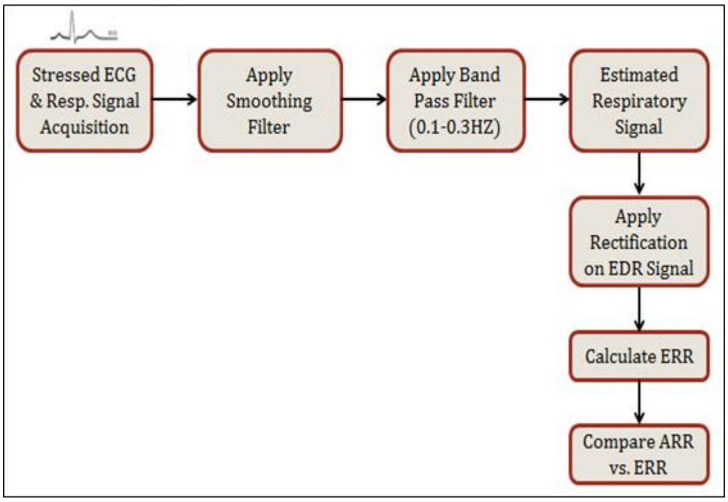

Fig-4: Flow Diagram of EDR using Filtering Concept Method

- 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.

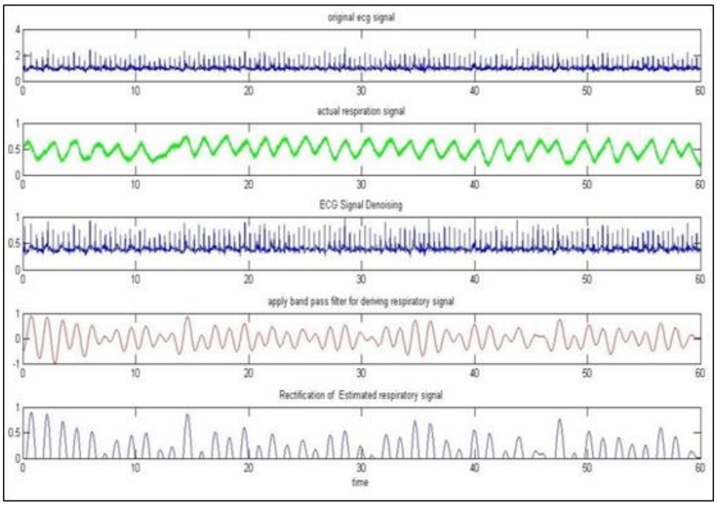

Fig-5: Implementation of EDR using Filtering Concept Method

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.

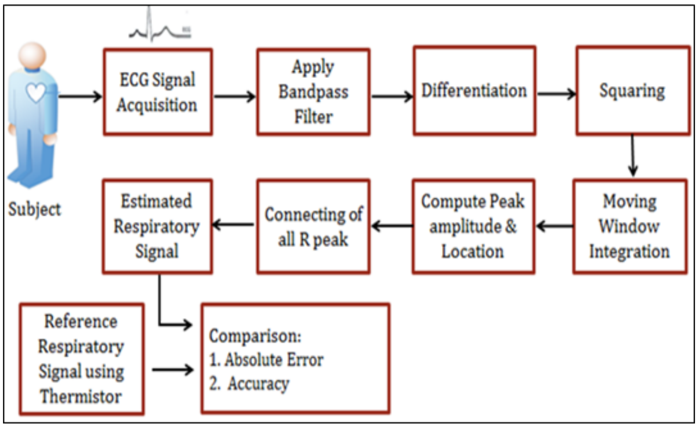

Fig-6: Block Diagram of EDR using R peak amplitude variation Method

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.

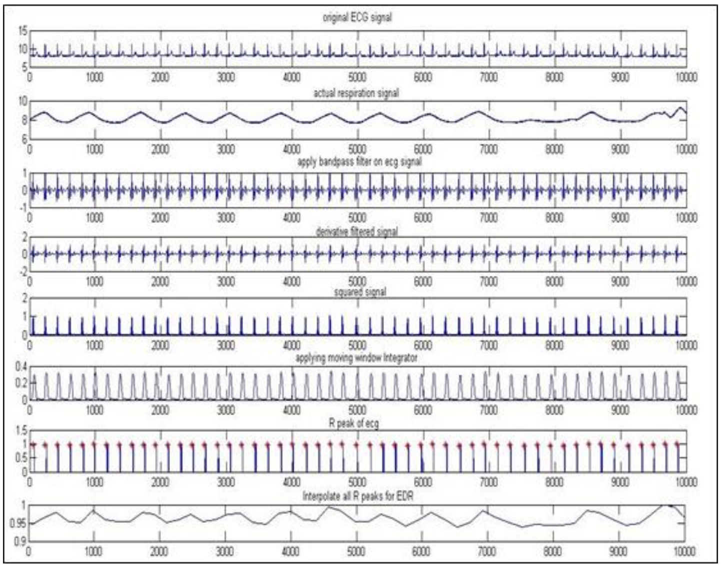

Fig-7: Implementation of EDR using R peak amplitude variation Method

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.

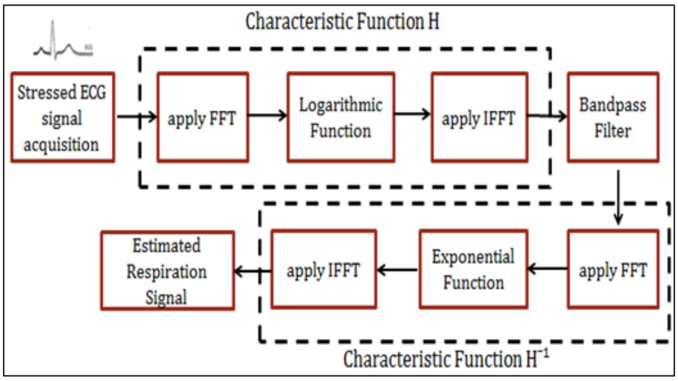

Fig-8: EDR using Homomorphic Filter Method

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: s1(n) and s2(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.

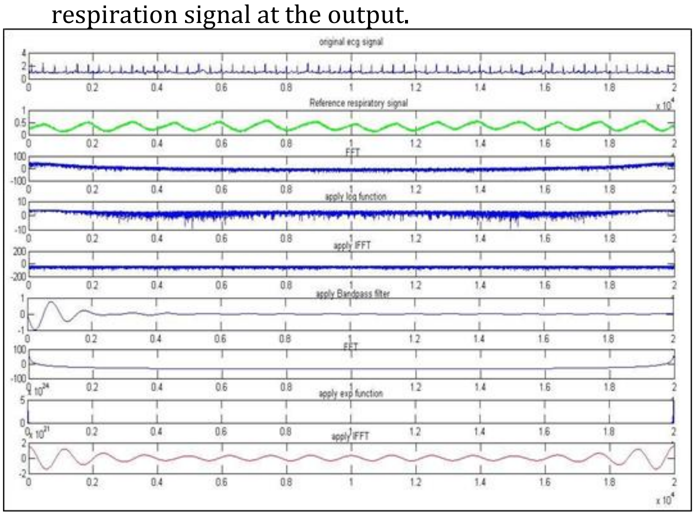

Fig-9: Implementation of EDR using Homomorphic Filter Method

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.

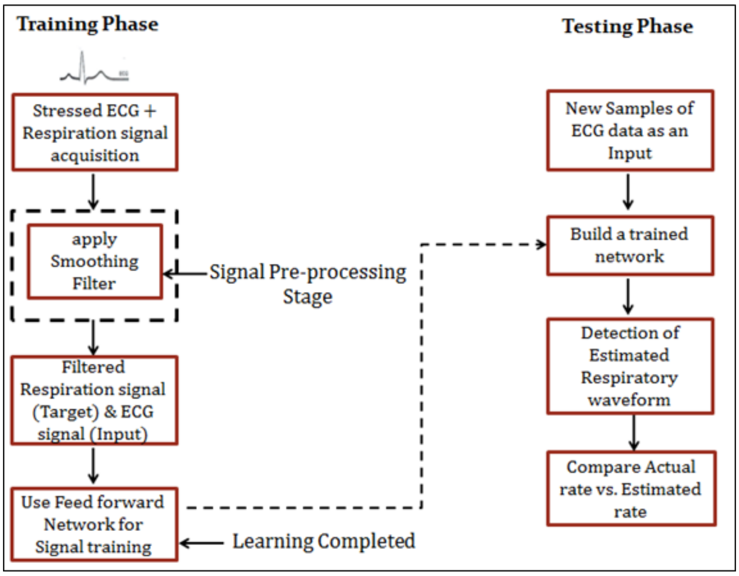

Fig-10: Flow diagram of EDR using Neural network Method

- During training phase, a set of samples of filtered ECG signal is taken as an Input and filtered respiration signal is taken as a target to generate reference patterns.

- Trained few samples of ECG signal using feed-forward network in which N=30 point hidden layer is used.

- During testing phase, another new sample of ECG data is taken as a new input, build a trained network and compare new samples of input data with reference patterns for detection of estimated respiratory waveform.

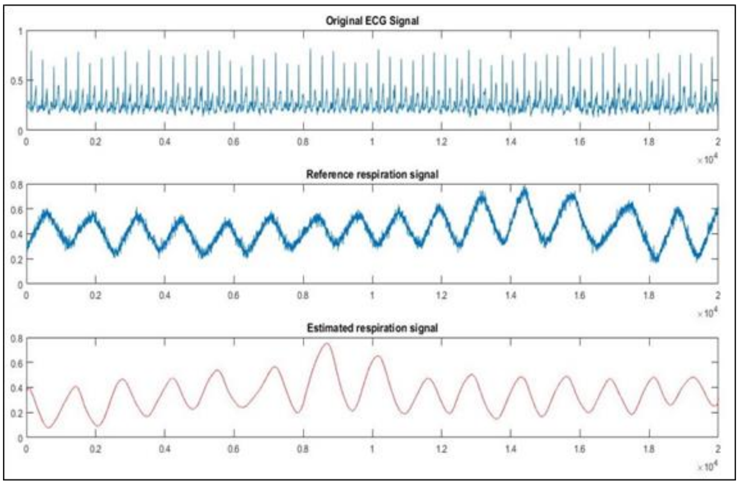

Fig-11: Implementation of EDR using Neural network Method

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.

Sr. No.	Gender	Age	Height (cm)	Weight (Kg)	HR- 1st Min	ARR- 1st Min	ERR For 1st Minute				
							M-I	M-II	M-III	M-IV	M-V
1.	Female	17	155	62	118	42	27	41	41	40	40
2.	Female	18	156	68	103	34	34	36	32	34	34
3.	Female	18	165	45	114	26	32	32	28	29	28
4.	Female	19	162	47	107	37	35	35	36	35	36
5.	Male	20	160.5	49	115	32	31	29	32	34	32
6.	Male	20	172	63	117	38	32	39	34	37	37
7.	Male	21	155	49	121	30	37	34	31	32	31
8.	Male	21	173	73	127	38	32	41	34	36	36
9.	Male	22	173	52	113	36	31	34	35	33	34
10.	Male	22	168	50	115	24	30	27	27	26	26
11.	Female	23	157	58	118	26	29	30	26	26	26
12.	Male	24	179.5	74	124	36	32	33	34	36	35
13.	Male	24	161	70	122	35	43	39	33	34	34
14.	Male	27	169	83	115	45	37	40	39	41	43
15.	Female	28	156	81	124	41	36	39	38	38	39
Average Absolute Error (%)							15.77	9.28	6.01	5.22	3.68
Accuracy (%)							84.23	90.72	93.99	94.7	96.32
Correlation Coefficient (r): ARR & ERR							0.22	0.84	0.96	0.97	0.99

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

Sr. No.	Gender	Age	Height (cm)	Weight (Kg)	HR- 5th Min	ARR- 5th Min	ERR For 5th Minute				
							M-I	M-II	M-III	M-IV	M-V
1.	Female	17	155	62	121	38	29	34	40	36	37
2.	Female	18	156	68	119	37	34	39	36	36	36
3.	Female	18	165	45	124	30	34	38	35	33	32
4.	Female	19	162	47	113	40	25	45	40	38	38
5.	Male	20	160.5	49	127	36	30	32	29	40	38
6.	Male	20	172	63	129	39	33	41	34	35	37
7.	Male	21	155	49	132	33	44	37	35	34	34
8.	Male	21	173	73	134	39	35	42	43	37	37
9.	Male	22	173	52	125	38	30	41	43	33	35
10.	Male	22	168	50	137	31	33	37	34	35	33
11.	Female	23	157	58	131	35	31	31	40	36	36
12.	Male	24	179.5	74	136	39	44	32	37	38	38
13.	Male	24	161	70	134	38	45	40	32	36	36
14.	Male	27	169	83	134	40	32	33	36	42	42
15.	Female	28	156	81	139	41	33	37	39	39	39
Average Absolute Error (%)							17.86	12.02	9.72	6.61	4.72
Accuracy (%)							82.14	87.98	90.28	93.39	95.28
Correlation Coefficient (r): ARR & ERR							-0.14	0.18	0.36	0.58	0.84

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

Sr. No.	Gender	Age	Height (cm)	Weight (Kg)	HR- 9th Min	ARR- 9th Min	ERR For 9th Minute				
							M-I	M-II	M-III	M-IV	M-V
1.	Female	17	155	62	137	45	34	34	40	39	39
2.	Female	18	156	68	120	45	32	40	49	37	38
3.	Female	18	165	45	131	39	31	39	43	36	36
4.	Female	19	162	47	123	46	31	34	31	32	38
5.	Male	20	160.5	49	134	41	31	39	41	38	38
6.	Male	20	172	63	133	44	33	40	39	37	39
7.	Male	21	155	49	141	40	39	33	37	37	37
8.	Male	21	173	73	139	38	37	37	47	37	37
9.	Male	22	173	52	143	49	34	39	46	45	45
10.	Male	22	168	50	147	36	33	42	40	34	34
11.	Female	23	157	58	152	49	31	37	52	43	45
12.	Male	24	179.5	74	143	42	48	35	48	46	45
13.	Male	24	161	70	141	39	41	44	49	41	41
14.	Male	27	169	83	147	32	48	42	45	45	40
15.	Female	28	156	81	153	49	32	36	46	46	46
Average Absolute Error (%)							22.72	16.30	14.36	12.66	9.87
Accuracy (%)							77.28	83.70	85.64	87.34	90.13
Correlation Coefficient (r): ARR & ERR							-0.55	-0.45	0.09	0.20	0.59

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 another 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:

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

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.

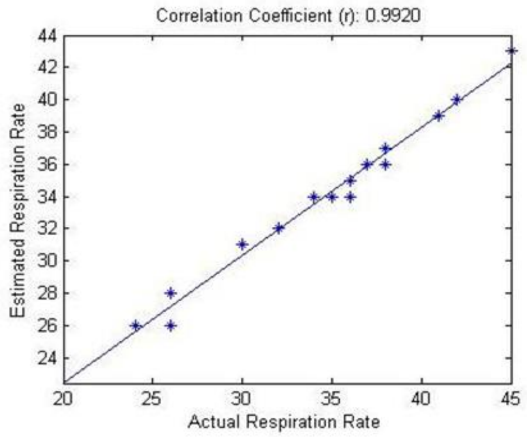

Fig-12 (a): Correlation coefficient (r) between ARR & ERR using neural network method (1st stage): 0.9920

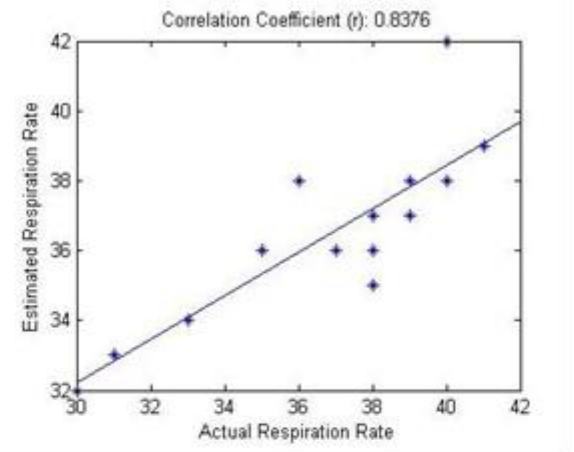

Fig-12 (b): Correlation coefficient (r) between ARR & ERR using neural network method (2nd stage): 0.8376

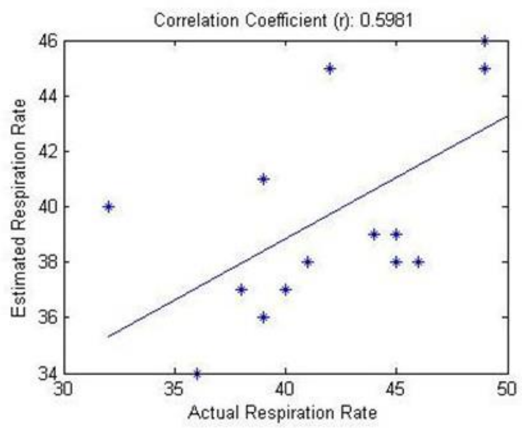

Fig-12 (c): Correlation coefficient (r) between ARR & ERR using neural network method (3rd stage): 0.5981

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 average 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.

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