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Reconstruction of respiratory signal from ECG

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Abstract - *Electrocardiography is a method used to record electrical activity of heart and the record of electrical activity of heart is known as electrocardiogram (ECG). Stress ECG is the test that checks for changes in your heart while you exercise. ECG and Stress ECG may be useful for diagnosis of cardiovascular disorders. In general practice, ECG is recorded using clinically accepted standard lead configuration with electrodes placed on the body surface. The recorded ECG is contaminated with interference due to body movements and respiration commonly called artifacts. ECG with artifacts may introduce error in computation of ECG parameters. Frequency ranges of ECG (0.02-150 Hz) and respiration (0.2-2 Hz) are overlapping. Use of digital filter is not suitable for suppression of artifacts in ECG. Adaptive filter needs respiration signal as a reference for suppression of artifacts. ECG free respiration signal may be recorded by sensing the respiration at nostrils using thermistor. Thermistor may cause error in signal due to self-heating and slow response in case of fast breathing during or just after exercise. Respiration related signals can be obtained using ECG. The features of ECG such as amplitude of R- peak, P-peak, T-peak Q-valley and S-valley, R-R interval, wavelet and empirical mode decomposition methods can be used for extraction of respiratory signal.*

Key Words: Electrocardiogram, cardiovascular diseases, respiration signal, Thermistor, Empirical Mode Decomposition.

1. INTRODUCTION

The electrocardiogram (ECG) is a record of an electrical activity of cardiac muscle. Stress ECG is a record of electrical activity of heart during exercise. ECG and stress ECG are routinely used for diagnosis of cardiovascular disorders. ECG is contaminated with signals related to body movements and respiration during recording commonly called as artifacts. This may cause difficulty in extracting diagnostic information from ECG. The frequency bands of ECG and respiration signal are overlapping. The use of filter for separation of respiration signal from ECG is not suitable. Wavelet based methods and adaptive filtering can be used for suppression of respiratory artifacts in ECG. Adaptive filtering requires reference signal for suppression of respiratory artifacts. Simultaneously recorded respiration signal can be used as a reference for adaptive filter. Along with ECG respiration signal can be recorded using thermistor at nostrils, strain gauge around the abdomen and capacitive or inductive transducer. Uses of these transducers for picking up respiratory signal are more prone to motion artifacts. Picking up respiration signal using thermistor at nostril have limitation in its use during exercise or in fast breathing rate. Respiratory signals are traditionally recorded by devices such as pressure sensors attached to a strain gauge or thermistor placed at the nostrils. However, the transducer used for sensing the respiration signal may interfere with natural breathing. Also the use of transducers is not suitable in ambulatory or long-term monitoring. Use of noisy respiratory signal as a reference for adaptive filtering does not suppress the respiratory artifacts effectively. Therefore, the development of a convenient method for extraction of respiratory signal using ECG is needed which may be used for suppression of respiratory artifacts in ECG.

Various methods have been proposed by several investigators to derive respiration signal from ECG called ECG-derived respiration (EDR) [2]. Felblinger et al. [2] used R-peak amplitude to obtain EDR. Moody et al. [13] reported a method for EDR based on area of normal QRS complex. Shuxe el al. [4] investigated use of ECG R-peaks for EDR. Murtaza at al. [12] derived respiratory signal from ECG. Domenico et al. [3] compared empirical mode decomposition and wavelet decomposition techniques to derive respiratory signal using ECG. They reported both techniques have better results with empirical mode decomposition technique slightly superior over wavelet decomposition. A wavelet based technique to derive respiration signal using Photo-Plethysmography (PPG) was reported [15]. The PPG derived respiration signal was compared with recorded respiration signal. They reported good agreement between the two signals.

It is proposed to reconstruct the respiration signal using features of ECG such as R-R interval, R-peak, P-peak, T-peak, Q and S valleys. Use of wavelet transformation and empirical mode decomposition is also proposed. The features of reconstructed respiration signal are compared to the simultaneously recorded respiration signal.

2. MATERIAL AND MATHODS

In this proposed methods ECG signals were recorded in lab set-up from 5 healthy subjects at rest. It includes electrodes used to pick-up surface potential in standard lead-II configuration. The signal picked up by ECG electrodes is fed to the amplifier with high gain, high input impedance, high CMRR and adequate frequency band. The respiratory signal was recorded along with ECG. For respiratory signal we use respiratory rate monitor. Respiration signal may be recorded by sensing the respiration at nostrils using thermistor. Also ECG signals and respiratory signal were taken from the Physionet [17]. Two databases were used Apnea-ECG database and MIT-Polysomnographic database(MIT-PMG).

The sampling rate of the signal is digitized at 500Hz in recorded database, 100 Hz in Apnea-ECG database and 250Hz in MIT-Polysomnographic database. Four records taken from Apnea-ECG and fourteen records from MIT-Polysomnographic database. The duration of samples taken is one minute.

ECG R-peaks were detected using Pan and Tompkins QRS detection algorithm. The algorithm includes low pass and high pass filtering of ECG, derivative, squaring, integration, and adaptive thresholding [11]. The P and T peaks and Q and S valleys were detected using R-peak as a reference. The successive R-peaks were joined and smoothened using cubic spline interpolation to give respiration signal.

The time interval between successive R-peaks were measured and called as R-R intervals. The successive RR-intervals were plotted against interval number to give respiration signal.

ECG was decomposed into 12 levels using db-6 wavelet. The 9th detailed level of decomposition was taken as respiration signal. In empirical mode decomposition ECG was decomposed into 12 levels and 9th IMF was taken as derived respiration signal.

3. Results and Discussion

The results were computed with comparison of eight EDR techniques with actual respiration, the mean error, standard deviation and correlation between ARR and ERR for all are calculated.

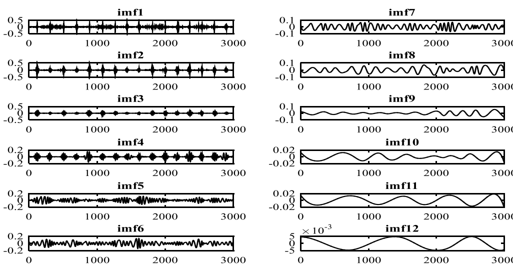

Fig -1: Different IMFs obtained by performing EMD

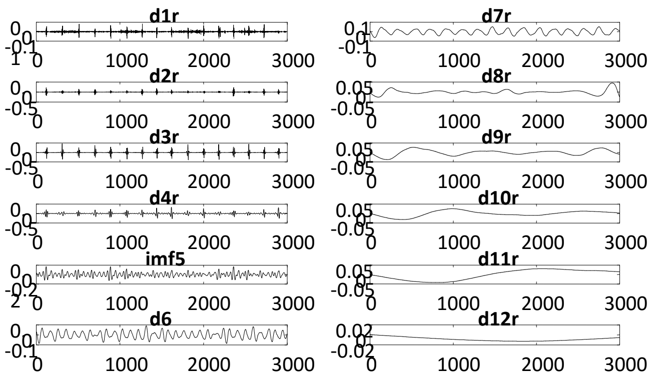

Fig -2: Detailed levels of wavelet decomposition

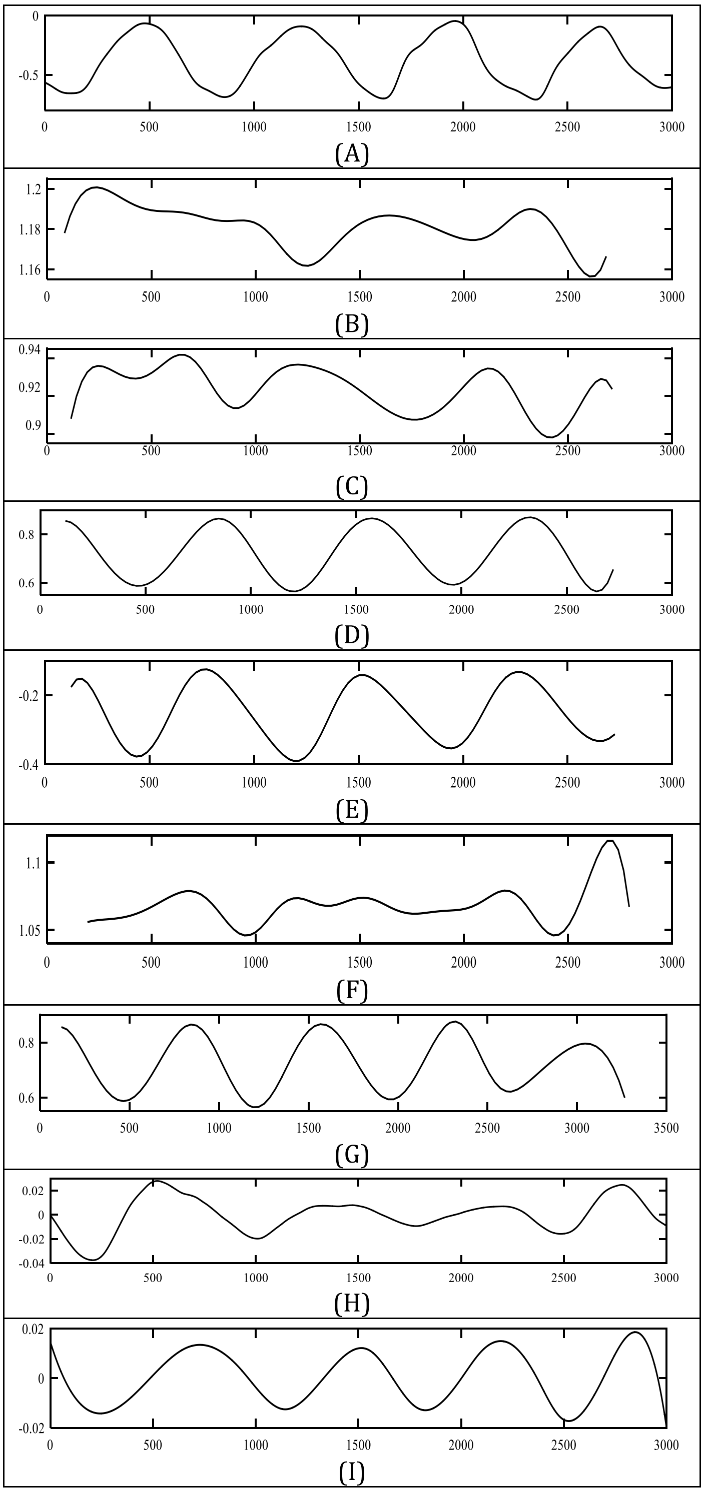

Fig -3: Comparison between (a) original respiration signal. (b) EDR using P-peak. (c) EDR using Q-valley. (d) EDR using R-peak. (e) EDR using S-valley. (f) EDR using T-peak. (g) EDR using RR intervals. (h) EDR using wavelet decomposition. (i) EDR using empirical mode decomposition.

Table -1: Comparison of respiration rate. (ARR: Actual respiration rate (breaths/ min) using respiration signal, ERR: Estimated respiration rate (breaths/ min) using method, M1: ECG derived respiration rate using P-peak, M2: ECG derived respiration rate using Q-valley, M3: ECG derived respiration rate using R-peak, M4: ECG derived respiration rate using S-valley, M5: ECG derived respiration rate using T-peak, M6: ECG derived respiration rate using RR interval, M7: ECG derived respiration rate using wavelet decomposition, M8: ECG derived respiration rate using empirical mode decomposition).

Data base	Record/ HR	ARR	ERR							
			M1	M2	M3	M4	M5	M6	M7	M8
Normal ECG	Sub1/73	26	27	25	23	22	24	23	27	25
	Sub2/98	31	30	34	30	33	31	30	28	31
	Sub3/72	25	22	25	20	21	22	22	21	25
	Sub4/106	24	28	20	21	20	19	19	28	23
	Sub5/85	33	28	33	31	34	30	31	42	29
Apnea ECG	b01_er/70	14	14	13	22	15	15	22	11	10
	c01_er/59	14	14	15	16	15	9	16	13	10
	c02_er/63	14	15	15	16	16	9	16	18	11
	c03_er/50	15	15	15	15	16	9	16	18	12
MIT-PMG	slp01a/65	13	13	12	10	17	11	10	15	16
	slp01b/60	11	12	8	11	12	4	11	12	14
	slp02a/93	23	27	20	22	22	22	22	23	19
	slp02b/78	21	20	22	20	20	20	20	26	23
	Slp03/72	16	16	17	16	16	17	16	15	20
	Slp04/74	10	12	16	17	13	16	17	10	12
	Slp14/67	17	15	16	15	15	18	15	15	12
	Slp16/87	25	21	24	24	22	27	24	23	18
	Slp32/70	14	16	19	14	12	12	9	26	13
	Slp37/81	24	24	24	20	18	23	20	25	21
	Slp48/60	12	11	17	10	9	13	10	15	12
	Slp60/79	24	16	24	16	22	21	16	24	24
	Slp61/72	21	15	26	19	19	21	18	23	25
	Slp66/73	19	13	14	17	18	19	18	14	17

Table -2: Statistical analysis of performance of methods for ECG derived respiration signal using methods implemented for different database. (ARR: Respiration rate ,breaths/ min, using respiration signal, ERR: Estimated respiratory rate, breaths/ min, using method, M1: ECG derived respiration rate using P-peak, M2: ECG derived respiration rate using Q-valley, M3: ECG derived respiration rate using R-peak, M4: ECG derived respiration rate using S-valley, M5: ECG derived respiration rate using T-peak, M6: ECG derived respiration rate using RR interval, M7: ECG derived respiration rate using wavelet decomposition, M8: ECG derived respiration rate using empirical mode decomposition, $\bar{\varepsilon}$: Mean Error (breaths/ min), s.d.: Standard Deviation(breaths/ min), r : Correlation coefficient)

Method	Index	Normal ECG	Apnea ECG	MIT-PMG	All
M1	$\bar{\varepsilon}$	0.8	−0.3	1.4	0.9
	s.d.	3.5	0.5	3.5	3.1
	r	0.5	0.6	0.8	0.9
M2	$\bar{\varepsilon}$	0.4	−0.3	−0.6	−0.2
	s.d.	2.5	1.0	3.4	2.9
	r	1.0	0.3	0.8	0.9
M3	$\bar{\varepsilon}$	2.8	−3	1.4	1.4
	s.d.	1.9	3.2	3.2	3.4
	r	1.0	−0.5	0.8	0.9
M4	$\bar{\varepsilon}$	1.8	−1.3	1.1	0.7
	s.d.	3.0	0.5	2.5	2.6
	r	1.0	0.6	0.9	0.9
M5	$\bar{\varepsilon}$	2.6	3.8	0.4	1.3
	s.d.	1.8	3.2	2.9	2.9
	r	1.0	−0.3	0.9	0.9
M6	$\bar{\varepsilon}$	2.8	-3.3	1.7	1.1
	s.d.	1.5	3.2	3.31	3.6
	r	1.0	−0.3	0.8	0.8
M7	$\bar{\varepsilon}$	−1.4	−0.8	−1.1	−0.9
	s.d.	5.3	3.3	4.0	4.0
	r	0.8	0.6	0.7	0.9
M8	$\bar{\varepsilon}$	1.2	3.5	0.3	1.0
	s.d.	1.6	0.6	3.5	3.1
	r	0.9	0.9	0.8	0.9

The results of reconstructed respiration signals using ECG P peak, Q valley amplitude, R peak amplitude, S valley amplitude, T peak amplitude, R-R intervals and wavelet decomposition are shown in Figurethe time values of time intervals measured using simultaneously recorded ECG and respiratory signals were statistically analyzed.

3. CONCLUSIONS

This paper presents eight methods for reconstruction of respiratory signal from single channel ECG. It is shown that all methods used are able to reconstruct respiratory signal.

In order to identify the performance of proposed methods three simple measures mean error, standard deviation and correlation of ARR and ERR were calculated. The mean error is in the range – 0.9 to 1.4 breaths/min, s.d. 2.6 to 40 breaths/ min, and correlation coefficient 0.8 to 0.9. All methods are equall efficient to derive respiration signal using ECG.

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