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Identification of Motion Artifact in Ambulatory ECG Signal Using Wavelet Techniques

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Abstract ECG signal are widely used in all over world to find various cardiac disorder, in today's world ambulatory ECG signal recording and monitoring becoming a popular using wearable AECG monitor and patient can do his daily routine life for timely diagnosis and treatment of cardiac disorder, but Ambulatory ECG signal is contaminated by motion artifact due to physical body movement so it must be removed before proper clinical analysis of AECG. We have recorded AECG signal using self made AECG recorder (Wearable device). Here four types of physical movement data taken like right hand movement, sitting to stand movement, waist and walking movement with faster and slower pace of five healthy person. We denoised AECG signal and identified motion artifact of different four physical activity using wavelet techniques. We have also taken videos of different physical activity to analyze and verify motion artifact in AECG signal.

Keywords AECG, Physical Activity (PA), Motion Artifact, Wavelet Transforms (WT), Wearable Device (WD)

1. Introduction

Cardiovascular disease is the leading cause of death in worldwide. Considering the fact that a majority of such deaths due to cardiac arrest occur before the patient can get the needed medical care, the patient should be continuously monitored for real time detection of the events of cardiac arrest and timely treatment. In recent years ambulatory ECG monitoring become popular for long term cardiac monitoring because they are convenient to use and serve as an option to the hospitalization. With an AECG device the ECG signal can be recorded or monitored in ambulatory conditions where the patient can perform all the routine activity. However, the effectiveness of AECG can be significantly impaired by motion artifacts which contaminates the signal and that can lead to errors in estimation of cardiac parameters and trigger false alarms. In ambulatory monitoring skin stretching due to body or limb movement or physical activity (PA) is a main cause of motion artifacts in AECG signals. The motion artifact induced due PA has a spectral overlap with ECG signal in 1-10 Hz[2]. Many important cardiac features of ECG signal like P and T wave has significant energy content in this overlapping band of 1-10Hz. So it is very difficult to separate or eliminate motion artifact completely without affecting these cardiac features in AECG[2]. Therefore researchers have developed various techniques to removal of motion artifact from AECG signal. The AECG is superposition of two independent events: the cardiac signal (ECG) and the motion artifact induced due to the PA as shown in fig. 1 is an AECG signal. Since Electronics circuits in AECG devices may themselves add sensor noise in the acquired electrical signal from the electrodes, the AECG signal sample r(n) in digital form can be modeled as sample-wise addition of three different signal components at n^{th} instance of time.

$$r(n) = q(n) + s(n) + \alpha(n) \quad (1)$$

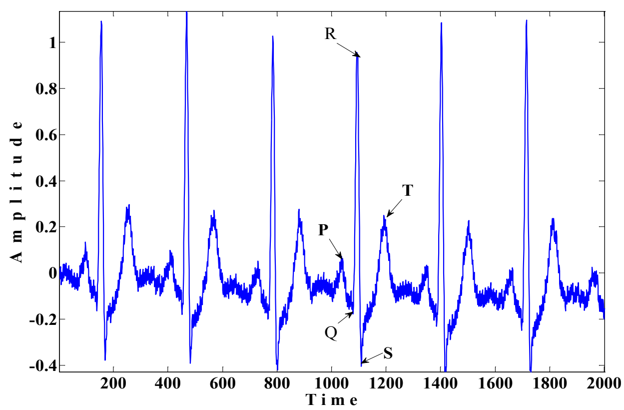

Figure 1. Ambulatory ECG signal

Where q(n), s(n) and α(n) are samples of cardiac signal, motion artifact signal and sensor noise, respectively. The mathematical model in (1) used for representing the AECG has been proposed in[3-4].

There are various methods used for AECG signal analysis and to remove artifact, like wavelet based methods are

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extensively used in pre-processing, denoising and analysis of ECG signals, adaptive filter based methods used for ECG signal processing and to remove motion artifact, neural networks also used for detection of events and pattern classifications in AECG signal analysis, the AECG is analyzed beat-by-beat using a recursive principal component analysis (RPCA) based method in[2].

In this paper wavelet based method used for AECG signal denoising and identification of motion artifact for different types of physical movement using graphical interface tool of MATLAB software and wavelet functions. We have used low cost AECG recorder for data acquisition process at sampling frequency of 500 Hz. AECG signal acquired and stored in pc at Lead –II configuration. We have also taken a video of different physical activity and compared video based analysis with automated analysis for motion artifact accurate verification.

2. Ambulatory ECG Data Acquisition

There are many Wearable AECG recorders available in market. We used self made Wearable ECG recorder that is customized, light weight, compact, battery operated, low power dissipation, low cost device and a person can easily carry with him in a wearable clothes. It can record ECG in digital format at various sampling rate. It consist wireless transceiver, microcontroller on board with software for ECG recording as shown in fig. 2.

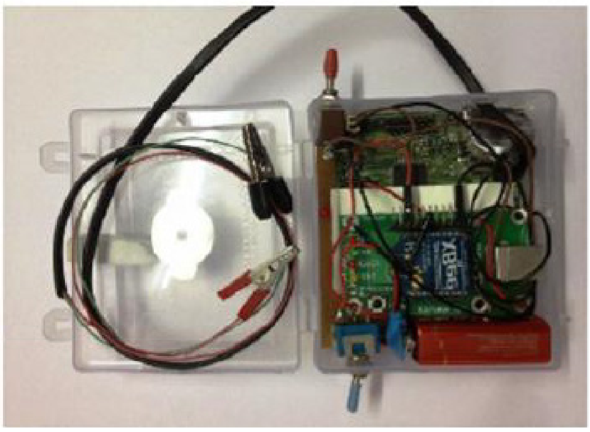

Figure 2. AECG monitor for ECG recording

AECG parameter can be displayed on Laptop or PC using LABVIEW software and also it can store in PC. Here AECG recorded for different type of physical activity. We have performed four type of body movement activity of healthy person and recorded AECG for (1) Right arm movement (2)) Sitting up and down from standstill (3) Twisting of waist and (4) Walking for short duration with slow and faster pace of five healthy people and corresponding video recorded for verification of identified motion artifact.

3. Motion Artifact Identification Using Wavelets

Wavelet analysis widely used in today's world in science and engineering field especially signal processing, biomedical area, image processing, communication area and other application area. Wavelet is a math function that is used to divide a given function into different component and it is reversible. A wavelet transform is the representation of a function by wavelets for representing functions that have discontinuities and sharp peaks, and for accurately deconstructing and reconstructing finite, non-periodic and/or non-stationary signals like ECG signal. There are wavelet based technique can be used for ECG signal analysis based on Discrete Wavelet Transform (DWT), Multiresolution DWT, Fast Wavelet Transform (FWT), Lifting Wavelets, Multiwavelet Transforms, Stationary Wavelet Transform (SWT), Wavelet Packet Decomposition (WPD), Fractional Wavelet Transform (Fractional WT) and Shrinkage and Threshold Methods[5].

We use the wavelet toolbox of matlab software and wavelet functions to analyze the AECG signal with motion artifact. Wavelet Toolbox provides functions and an application for developing wavelet-based algorithms for the analysis, synthesis, denoising, and compression of signals and images in 1-D and 2-D[7]. We performed a multilevel, a level 8 decomposition of the AECG signal with motion artifact using the biorthogonal wavelet. There are many wavelet families like Daubachies, Coiflets, Symlet, Biorthogonal, Meyer, Mexican Hat, Morlet etc available. In this paper biorthogonal family wavelets is used, biorthogonal wavelet transform has frequently been used in numerous image and signal processing applications, because it makes possible multiresolution analysis and does not produce redundant information[6]. The graphical interface tools feature a de-noising option with a predefined thresholding strategy. This makes it very easy to remove noise from a signal. Level 8 a Multilevel 1-D decomposition which contain approximation and detail component of low pass filter and high pass filter respectively, that is used to reconstruct the signal. Reconstructed signal have following approximation and detail component

$$X1 = A8 + D1 + D2 + D3 + D4 + D5 + D6 + D7 + D8 \quad (2)$$

While motion artifact signal identified by from

$$M1 = X1 - A8 - D8 \quad (3)$$

Here X1 is reconstructed signal while M1 is identified motion artifact. As shown in fig. 3 identified motion artifact superimposed on AECG signal, for slow hand movement. Here fig. 3(a) contain ambulatory ECG signal with motion artifact due to continuously right hand movement at slower pace while fig. 3 (b) indicates identified motion artifact and its peaks while fig. 3(c) indicates AECG signal with separated motion artifact. In fig. 4 histogram of fast hand movement shown, which also shows slower and faster movement have different motion artifact peak interval density. We have identified motion artifact in most common physical movement as per shown in table 1 and corresponding motion artifact is identified for all. Table 1 and 2 shows parameters of motion artifact for hand movement of five people, they are mean value of peaks of motion artifact, peak interval, percentage of standard deviation of peak interval , valley and valley interval of motion artifact in persons 1,2,3,4 and 5 of hand movements at faster pace while table 2 shows for slow physical hand movement. Here number of peaks and valley in motion artifact is increases in fast movement compared to slow physical movement while peak interval and valley decrease of person 1,2,3,4, and 5 as per table 3 and 4. Table 5 shows comparison of video based physical movement analysis with automated analysis for verification of motion artifact identification. We verified also for slow and fast physical movement for four type of activity of one person. We find that peak interval of motion artifact for fast and slow physical movement of one person with all physical activity by automated analysis and from video analysis that is nearly same that justify that accurately motion artifact is identified. Table 6 shows physical movement interval by automated and video based analysis that also indicate slow movement have higher interval cycle/s than fast movement interval cycle/s for all four physical activity and it also indicate hand and walking movement lower interval cycle/s than waist and seat to stand interval cycle/s.

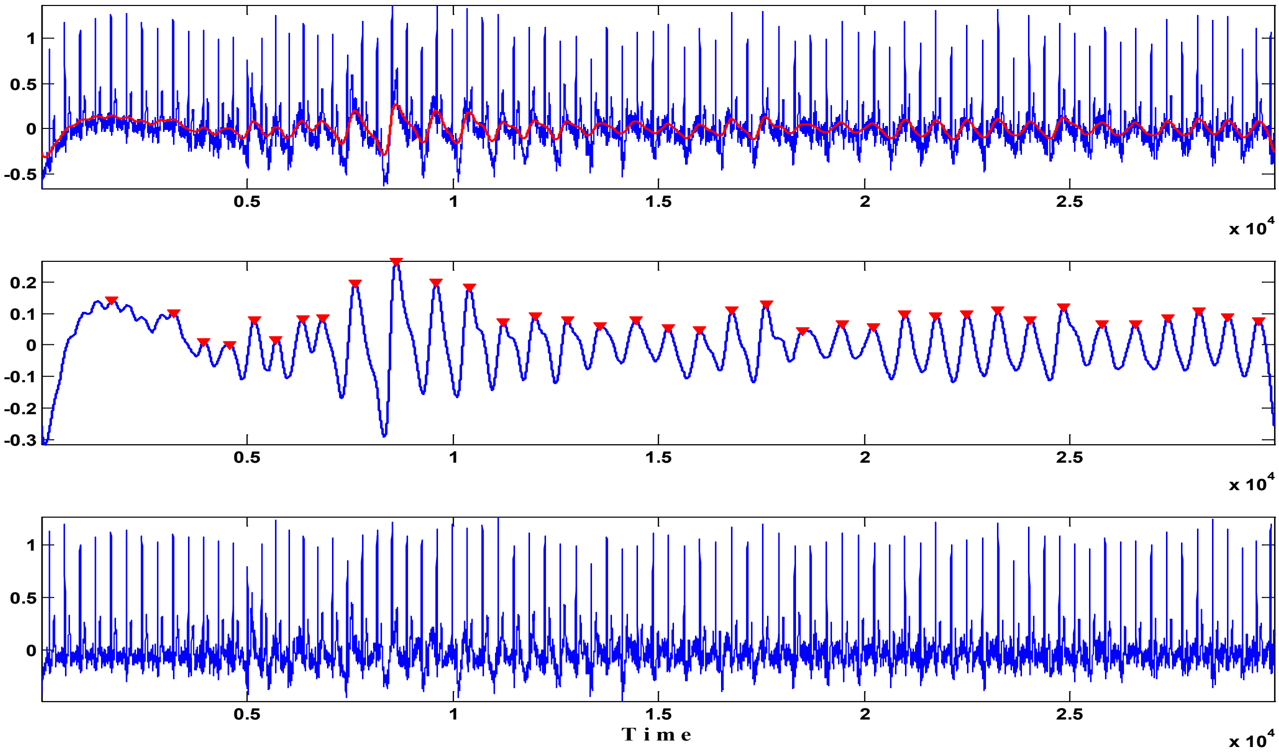

Figure 3. Identification of motion artifact for right hand up down slow movement

Table 1. Fast hand movement

Person #	Peak Interval	No. of peak	% STD	Valley Interval	No. of valley
Person 1	634	44	7	637	45
Person 2	587	55	27	501	57
Person 3	747	36	42	808	35
Person 4	830	31	44	919	31
Person 5	452	63	133	452	63
Total Mean	**650**	**45**	**50**	**663**	**46**

Table 2. Slow hand movement

Person #	Peak Interval	No. of peak	% STD	Valley Interval	No. of valley
Person 1	856	43	41	657	44
Person 2	614	47	37	601	47
Person 3	918	31	35	930	31
Person 4	743	37	26	729	37
Person 5	686	41	17	686	42
Total Mean	**763**	**39**	**31**	**720**	**40**

Table 3. Motion artifact interval parameter mean value of five persons

Physical activity	Peak Interval	Peak No.	% STD	Valley Interval	Valley No.
Fast walk	609	50	59	612	50
Fast waist	680	41	33	692	42
Fast seat	782	38	25	787	40
Fast hand	650	45	50	663	46
Total mean	**680**	**43**	**41**	**688**	**44**

Table 4. Motion artifact interval parameter mean value of five persons

Physical activity	Peak Interval	Peak No.	% STD	Valley Interval	Valley No.
Slow walk	903	33	49	907	33
Slow waist	1132	26	40	1116	26
Slow seat	1039	29	38	1045	29
Slow hand	763	39	31	720	40
Total mean	**959**	**31**	**39**	**947**	**32**

Table 5. Comparison of automated analysis with video based analysis for slow hand movement for 60 second

Peak#	Peak Position (n)	Peak Interval (n)	Peak Time Interval (s)	Time(s)	Time from video(s)	Video time Interval (s)
1	1695	0	0	0	0	0
2	3202	1507	3.014	3.014	3	3
3	3939	737	1.474	4.488	4	1
4	4586	647	1.294	5.782	5	1
5	5164	578	1.156	6.938	6	1
6	5693	529	1.058	7.996	8	2
7	6343	650	1.3	9.296	9	1
8	6831	488	0.976	10.272	11	2
9	7623	792	1.584	11.856	13	2
10	8620	997	1.994	13.85	15	2
11	9601	981	1.962	15.812	16	1
12	10401	800	1.6	17.412	18	2
13	11231	830	1.66	19.072	20	2
14	11994	763	1.526	20.598	21	1
15	12779	785	1.57	22.168	23	2
16	13583	804	1.608	23.776	24	1
17	14434	851	1.702	25.478	26	2
18	15235	801	1.602	27.08	28	2
19	16002	767	1.534	28.614	29	1
20	16772	770	1.54	30.154	31	2
21	17606	834	1.668	31.822	33	2
22	18507	901	1.802	33.624	34	1
23	19459	952	1.904	35.528	35	1
24	20228	769	1.538	37.066	37	2
25	20982	754	1.508	38.574	39	2
26	21733	751	1.502	40.076	40	1
27	22487	754	1.508	41.584	42	2
28	23246	759	1.518	43.102	44	2
29	24028	782	1.564	44.666	45	1
30	24833	805	1.61	46.276	47	2
31	25777	944	1.888	48.164	49	2
32	26589	812	1.624	49.788	50	1
33	27362	773	1.546	51.334	52	1
34	28125	763	1.526	52.86	53	2
35	28823	698	1.396	54.256	54	1
36	29581	758	1.516	55.772	56	2

Table 6. Comparison of automated analysis with video based analysis for all physical movement

Physical activity #	Fast movement interval cycle/s	Fast movement interval cycle/s from video	Slow movement interval cycle/s	Slow movement interval cycle/s from video
walk	0.9647	0.9407	1.4488	1.5000
waist	1.4098	1.4634	2.2428	2.2692
seat	2.1880	2.1923	3.4919	4.0000
hand	1.0265	1.0543	1.5492	1.5556

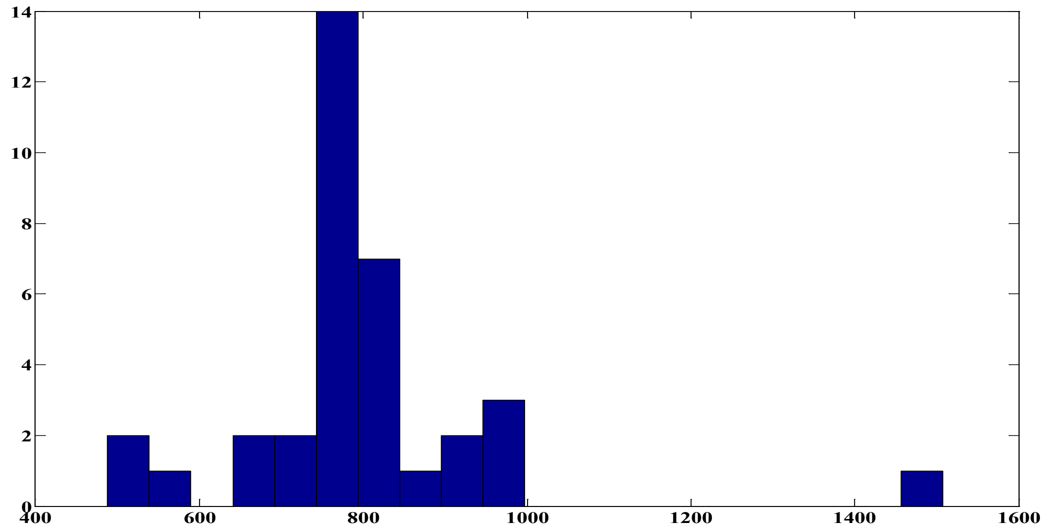

Figure 4. Histogram of motion artifact peak interval of right hand slow movement

4. Conclusions

In this paper we have recorded Ambulatory ECG signal of five healthy people with four type of physical activity like right hand movement, sitting to stand movement, waist and walking movement with faster and slower pace. We denoised AECG signal and identified motion artifact of different four physical activity using wavelet tool box of matlab software. We have also recorded videos of different physical activity to analyze and verify motion artifact in AECG signal is accurately identified for all physical activity. So the AECG signal of the patient should be continuously monitored for real time detection of the events of cardiac arrest and timely treatment of a person having cardiac abnormalities with motion artifact signal removed by wavelet methods can be used to diagnosis cardiac disorder by expert.

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