Simultaneous monitoring of motion ECG of two subjects using Bluetooth Piconet and baseline drift

Tejal Dave¹ · Utpal Pandya¹

Received: 1 February 2018 / Revised: 8 May 2018 / Accepted: 19 July 2018 / Published online: 31 July 2018
© Korean Society of Medical and Biological Engineering and Springer-Verlag GmbH Germany, part of Springer Nature 2018

Abstract

Uninterrupted monitoring of multiple subjects is required for mass causality events, in hospital environment or for sports by medical technicians or physicians. Movement of subjects under monitoring requires such system to be wireless, sometimes demands multiple transmitters and a receiver as a base station and monitored parameter must not be corrupted by any noise before further diagnosis. A Bluetooth Piconet network is visualized, where each subject carries a Bluetooth transmitter module that acquires vital sign continuously and relays to Bluetooth enabled device where, further signal processing is done. In this paper, a wireless network is realized to capture ECG of two subjects performing different activities like cycling, jogging, staircase climbing at 100 Hz frequency using prototyped Bluetooth module. The paper demonstrates removal of baseline drift using Fast Fourier Transform and Inverse Fast Fourier Transform and removal of high frequency noise using moving average and S-Golay algorithm. Experimental results highlight the efficacy of the proposed work to monitor any vital sign parameters of multiple subjects simultaneously. The importance of removing baseline drift before high frequency noise removal is shown using experimental results. It is possible to use Bluetooth Piconet frame work to capture ECG simultaneously for more than two subjects. For the applications where there will be larger body movement, baseline drift removal is a major concern and hence along with wireless transmission issues, baseline drift removal before high frequency noise removal is necessary for further feature extraction.

Keywords Ambulatory Electrocardiogram (AECG) · BluetoothTM Piconet · Wireless communication · Noise removal · Root mean square deviation (RMSD) · Serial port profile (SPP)

1 Introduction

Wireless ECG systems have been active research area for the past few years due to its flexibility to make use of receiver device either computer or mobile as a base station [1–5]. The wireless cardiac monitoring system has potential to monitor subjects continuously for an extended and unlimited period. It can decrease time for diagnosis and can improve subject health.

Reduction of motion artifacts is still an important problem for cardiac monitoring system because of overlapping of its frequency band with the desired signal [5]. Activities of a subject will pose an interference or artifact during acquisition procedure of ECG [6]. In lead ECG signal, baseline drift or low frequency noise can be caused due to breathing or coughing or leg movement during ECG acquisition. It may also due to temperature variation or bias in instrumentation amplifier [6]. The range of low frequency noise is 0.05–2 Hz. High frequency noise include power line interference noise, Electromyography noise etc. High frequency noise is caused due to pick up of ambient Electromagnetic signals [6] by the cables of recording system and the range of which falls within 5–70 Hz. The American Heart Association has recommended lowest cut-off frequency of 35 Hz to be considered for low-pass filtering [7]. Removal of noise from ECG is a necessary condition to be satisfied before extraction of feature like prominent QRS complex. QRS complex

✉ Tejal Dave
tejal.dave@scet.ac.in

Utpal Pandya
utpal.pandya@scet.ac.in

¹ Instrumentation and Control Engineering Department,
Sarvajanik College of Engineering & Technology, Gujarat
Technological University (GTU), Chandkheda, Surat-01,
Gujarat, India

indicates ventricular contraction of a heart and provides a base for automatic detection of heart rate [8]. The review of implementation of Bluetooth based ECG acquisition system suggests that for the case of wearable wireless system, it is required to study the effect of motion artifacts along with wireless transmission issues on the measurement of ECG [9]. Digital filters are used mostly by many researchers to remove noise in captured ECG. Discrete Wavelet transform is used for signal processing of ECG by Kang, Yun and Chao [10]. Sonpara et al. [11] have used 85th order Kaiser Window FIR bandpass filter to filter out all other portion of ECG except QRS complex frequency range at the base station. ECG signal is processed using two FIR low pass and high pass filters for attenuation of noise by Wcislik et al. [12]. Li et al. [13], in their work of ECG filter design for mobile medical system shows the complex design of IIR filter coefficients. Bortolan et al. [14] have been able to remove baseline drift partially in exercise ECG using two-way high-pass recursive IIR filter. Ko et al. [15] have demonstrated the use of adaptive filtering for motion artifacts removal. Bandpass filter of 1–150 Hz range has been designed for intelligent telecardiology system by Lin et al. [16]. Independent component analysis combined with adaptive filter is used by Luo et al. [17].

In this paper, Bluetooth Piconet is configured using two subjects for simultaneous monitoring of ECG. The paper addresses noise removal issues in applications where, multiple wireless transmitters send medical parameters to a single receiver. ECGs are captured simultaneously from two subjects doing activities like cycling, jogging and staircase climbing. The paper demonstrates sequential removal of various measurement noises by first removing baseline drift using Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) and then applying moving average, and Savitzky Golay (S-Golay) algorithm to remove high frequency noise. It is found out that baseline drift removal is a prerequisite step in wireless ECG processing.

Conventional recursive IIR filter appears to be computationally efficient compared to FFT-IFFT method for filtering required in complex, real time applications. The low frequency noise introduced in ECG varies with the activity of the subject while acquiring the signal. Conventional IIR filter does not take into account these variations. Here we are dealing with less number of data points and doing processing at base station. We have used FFT-IFFT filtering for ECG baseline drift removal.

FFT helps us to unfold the signal in frequency domain and enables us to identify exact locations of noise and then removes it dynamically. After taking FFT of the ECG signal; the FFT coefficients containing low frequency noise are assigned zero weight, and then the signal is reconstructed back to time domain by taking IFFT.

The paper is organized as follows: Sect. 2 describes materials and method for experimental work; Sect. 3 presents various experimental and simulation results carried out. Section 4 shows discussion on results and finally Sect. 5 includes conclusion and future scope of work.

2 Materials and method

Bluetooth Piconet is implemented for simultaneous monitoring of ECG of two subjects using prototype system. As shown in Fig. 1, system comprises of two transmitters and a receiver.

2.1 Prototype transmitter system

Analog front end available in the transmitter is used to sense ECG signal in mili-volt and it is converted into 0–5 V analog signal. Bluetooth module is another part of hardware which consists of serial Analog to Digital Converter (ADC), microcontroller and Bluetooth transceiver [18, 19].

2.2 Receiver system

Bluetooth enabled laptop (or mobile) is used as a base station, which receives data from prototype Bluetooth ECG transmitter. To establish Bluetooth connectivity, Bluesoleil software is used [20]. Figure 2 shows the picture of system setup with patient cables and disposable electrodes. The ECG can be picked up in the range of 100–1000 Hz depending on diagnostic requirements [18, 19]. In this study, ECG data is collected with sampling frequency of 100 Hz. The ECG data is acquired and converted to digital using ADC having 16 bit resolution in the range of 0–5 V.

Fig. 1 Block Diagram for Bluetooth Piconet for the measurement of ECG of two subjects

Fig. 2 Photograph of system hardware with disposable electrodes and subject cables

An open source terminal software (Tera-term Pro), which supports serial port profile, is used to collect ECG data. Received text file of ECG data (hexadecimal format) is imported to MATLAB to remove baseline drift and other high frequency noise.

2.3 Implementation of noise removal techniques

To keep the system low cost and easily adaptable, instead of using specific ECG electrode belt or block, widely used Ag/AgCl₂ disposable electrodes and standard three lead patient cables are used for ECG capturing. Due to different activities being performed by subject, a base line drift is likely to be present in received ECG signal. To remove baseline drift, after conversion of hexadecimal values to decimal values and applying scaling factor, very first, the Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) are performed on ECG data. FFT of signal $x[n]$ is given by Eq. 1.

$$X[m] = \sum_{n=0}^{N-1} x[n] e^{-j2\pi nm/N} \quad (1)$$

where $m = 0, 1, 2 \dots N/2$ for real signal, and N = length of Signal.

Absolute frequency of m th bin center is given by,

$$f = \frac{mFs}{N} \quad (2)$$

where F_s = Sampling frequency of ECG, N is length of ECG. Using Eq. 2, m is found to remove absolute frequency; and there amplitudes are made zero using following steps:

Step: 1 $X[m](1 : \text{round}(\frac{N}{F_s})) = 0$

Step: 2 $X[m](N - \text{round}(\frac{N}{F_s}) : N) = 0$

Suppose 4096 samples of ECG is captured at different sampling frequency, then to remove absolute frequency i.e. baseline drift of 1 Hz, the number of m bins whose amplitude are made zero at different sampling frequency is given in Table 1.

So, $X[n]$ in Eq. 3, which is IFFT of modified signal $X[m]$, is ECG signal without baseline drift.

$$X[n] = \sum_{m=0}^{N-1} X[m] e^{-j2\pi nm/N} \quad (3)$$

Resulted ECG signal is still carrying high frequency noise which is required to be filtered out without modifying ECG signal properties. Two algorithms namely (1) moving average and (2) S-Golay are implemented to remove high frequency noise from ECG signal after applying FFT-IFFT algorithms. A moving average is basically a low-pass filter. If n is the number of point for which averaging is required to be carried out and a_j is the sample values, then moving average algorithm is mathematically expressed as

$$s_i = \frac{1}{n} \sum_{j=i}^{i+n-1} a_j \quad (4)$$

where S_i is the new calculated value of samples averaged for n points. The second algorithm implemented is S-Golay smoothing filter. S-Golay filters are called digital smoothing polynomial filters or least-squares smoothing filters. It is a weighted moving average filter that operates on a specified order polynomial for the given frame size in a least-squares sense. In order to smooth out a noisy signal, S-Golay filters outperform standard averaging FIR filters, which may filter out a useful portion of ECG signal's content while trying to remove noise. S-Golay filters are optimal in minimizing least square error in fitting polynomial to frames of noisy data [21, 22].

The main advantage of this algorithm is it preserves features of relative maxima, minima and width, which are usually attenuated by other averaging techniques [19]. Table 2 summarizes the filter parameters of different algorithms used.

2.4 Performance indices

To evaluate the quantitative ability of the filtering algorithm to reconstruct ECG signal, we have used root mean square deviation (RMSD), and signal to signal plus noise ratio (SSNR) indices [20]. If filtering algorithm is not removing noise efficiently then RMSD value of such reconstructed ECG will be higher. The algorithm which is filtering more noise should have better SSNR values in comparison with other algorithm [20]. RMSD and SSNR are found by following Eqs. 5 and 6.

Table 1 No. of bins with zero amplitude

Sample frequency	Length of signal	No. of bins with zero amplitude
100	4096	0:40 and 4056:4096
200	4096	0:20 and 4076:4096
250	4096	0:16 and 4080:4096
500	4096	0:8 and 4088:4096

Table 2 Filter parameters for algorithms

Algorithm	Filter parameters
Moving average	Smoothing factor—4
S-Golay	Frame size—15
	Degree of polynomial—5

$$RMSD = \sqrt{\frac{\sum_{i=1}^n (ECG_{cap}(i) - ECG_{filt}(i))^2}{n}} \quad (5)$$

where $ECG_{cap}(i) = ECG_{signal}(i) + ECG_{noise}(i)$, ECG_{filt} is filtered signal and ECG_{cap} is captured noisy ECG signal, ECG_{signal} is noise free ECG.

$$SSNR = 20 \log_{10} \left(\frac{A_{filt}}{A_{cap}} \right) \quad (6)$$

where A_{filt} is amplitude of filtered signal and A_{cap} is amplitude of captured signal.

3 Results

In our earlier work [9], prototyped Bluetooth ECG boards were successfully tested to collect ECG of a subject at different sampling rate. In this study, the work is extended by realizing Bluetooth Piconet for monitoring of ECG of two subjects, simultaneously. In [18], Bluetooth Piconet is discussed and wireless transmission issues are highlighted. In this study, the work is extended by realizing Bluetooth Piconet for monitoring of ECG of two subjects doing large body movement activities, simultaneously as shown in Fig. 3.

During experimentation, each subject wears ECG electrodes along-with Bluetooth ECG module which is connected to laptop via Bluetooth link. Before capturing ECG of two subjects, Bluetooth modules are tested using synthesized ECG signal generated using programmable function generator. Figure 4 shows simulated ECGs received at laptop through two Bluetooth modules using Bluetooth link, respectively.

Fig. 3 Photograph of two subjects doing various activities when ECGs are being captured simultaneously using Bluetooth ECG module in Piconet mode. **a** Two subjects are climbing staircase, **b** two subjects are cycling

Fig. 4 Simulated ECGs received at laptop from **a** prototype unit 1 and **b** prototype unit 2 via-Bluetooth connection

ECG signals are captured at the same time for same two subjects performing various activities like cycling, jogging and staircase climbing. Wireless ECG received at base station for different activities of subject 1 and subject 2 are shown in Fig. 5a, b respectively. These signals are captured

Fig. 5 Received wireless ECG for activity like cycling, jogging, and stair-case climbing for **a** subject 1 and **b** subject 2 using 100 Hz sampling rate

simultaneously via Bluetooth link with duration of 20 min for both subjects while performing activities. However, signals for only 25 s duration has been considered for display.

To analyze the effect of base line drift, in first instance two filtering algorithms, i.e. moving average and S-golay algorithms are implemented on corrupted ECG received at base station while in second instance, filtering algorithms are implemented on ECG signals after baseline removal using FFT-IFFT algorithm.

Figure 7 shows filtering of same ECG when moving average and S-Golay algorithms are implemented after performing FFT-IFFT to remove baseline drift. Plot of Fig. 7a is same as Fig. 6a. Figure 7b shows the baseline corrected ECG using FFT-IFFT; Fig. 7c, d show significant improvement than Fig. 6b, c. It is clearly evident from Fig. 7 that better filtering of noise is achieved when

Fig. 6 **a–c** Filtering algorithms implemented on ECG received wirelessly for subject 2 during cycling

Fig. 7 Filtering algorithms moving average and S-Golay implemented on wireless ECG received for subject 2 during cycling after removal of base line drift

moving average and S-Golay algorithms are implemented after base line drift is removed from captured ECG.

Table 3 RMSD and SSNR values for algorithms

Algorithm	Without baseline removal		With baseline removal	
	RMSD	SSNR in db	RMSD	SSNR in db
Moving average	0.2584	0.0929	1.5991	7.6076
S-Golay	0.2209	0.0871	1.5934	7.5508

Fig. 8 The plot of filtered ECG when the subject 2 performing jogging

Table 3 shows statistics for both filtering algorithms implemented before and after baseline removal for ECG of Figs. 6 and 7.

Figure 6 along with higher values of RMSD and SSNR in Table 3, demonstrate the fact that in comparison to FFT-IFFT, moving average and S-Golay algorithms are not able to remove noise from ECG when there is a significant drift in baseline.

Filtering algorithms are applied on ECG for both subjects performing activities like cycling, jogging and staircase climbing that also results into more baseline drift. Subjects were instructed to run slowly and ride bicycle within the communication range of Bluetooth device.

Figures 8, 9 show results for subject 2 performing different activities. The processing of ECG signal of subject 2 when jogging is shown in Fig. 8 while Fig. 9 shows the ECG processing of same subject for climbing staircase. ECG signals are shown for initial 20 s.

Quantitative performance analysis is shown in Table 4 demonstrating RMSD values and SSNR values of different activities of subjects for first 2000 samples. These values are for moving average and S-Golay algorithms implemented after baseline removal using FFT-IFFT algorithm on captured ECG. From Table 4 it is clear that high RMSD and low SSNR are achieved for moving average and S-Golay when implemented along with FFT-IFFT algorithm.

Fig. 9 The plot of filtered ECG when the subject 2 climbing staircase

4 Discussion

The higher values of RMSD and low values of SSNR for moving average and S-Golay filter, illustrated in Table 4 indicate improvement when both the algorithms are implemented after baseline removal. When moving average is applied on baseline corrected ECG, results into better filtered waveform but there is significant attenuation in amplitude of QRS complex. With S-Golay, improved filtering operation is achieved and also QRS amplitude is preserved. However, similar to moving average, S-Golay also can not reduce low frequency noise component without consideration of FFT-IFFT. It is desired to remove baseline drift before filtering of high frequency.

5 Conclusion

Bluetooth Piconet network is implemented successfully using prototype hardware model for acquiring ECG of two subjects, simultaneously. The result suggests that it is possible to extend the network of subjects up to maximum seven into Bluetooth Piconet frame work to capture ECG at a time. By changing front end analog signal processing board only, it is possible to monitor any vital sign using Bluetooth Piconet formation.

The qualitative as well as quantitative analysis demonstrated here suggest that the prior removal of base line drift using FFT-IFFT algorithms improves filtering performance of algorithms used to remove high frequency noise from ECG signal.

Results also show that for continuous monitoring of subjects with large body movement, the frequency of

Table 4 RMSD and SSNR values for filtering algorithms

Subject position	Algorithm	Subject 1		Subject 2	
		RMSD	SSNR in db	RMSD	SSNR in db
Cycling	FFT-IFFT	3.0221	– 22.6876	1.5781	– 14.2679
	MA-4	3.0279	– 27.8251	1.5991	– 17.6076
	S-Golay	3.0277	– 27.8346	1.5934	– 17.5508
Jogging	FFT-IFFT	1.4769	– 19.5723	1.3070	– 15.2792
	MA-4	1.4812	– 21.8560	1.3212	– 18.8446
	S-Golay	1.4797	– 21.6068	1.3174	– 18.8134
Staircase climbing	FFT-IFFT	1.5921	– 19.5389	1.5042	– 13.8621
	MA-4	1.5979	– 22.8675	1.5232	– 16.4739
	S-Golay	1.5964	– 22.6428	1.5176	– 16.4394

motion artifact varies with different activities and also varies from subject to subject. This may requires a dynamic parameter adjustment of filtering algorithm to get the faithful reproduction of ECG signal for further diagnostic and to get clinical grade accuracy in wireless multiple subjects monitoring for ECG.

Conflict of interest Authors declare that they have no conflict of interest

Ethical statement We certify that the study carried out in non-invasive manner on healthy subjects with necessary ethical consideration.

References

- Grigorian ER, Adhami R, Toutonji O. Wireless ECG monitor. In: IEEE international workshop on computational advances in multi-sensor adaptive processing, 2007, p. 161–164.
- Kailanto H, Hyvarinen E, Hyttinen J. Mobile ECG measurement and analysis system using mobile phone as the base station. In: International conference on pervasive computing technologies for healthcare, Finland, Jan 30–Feb 1 2008, p. 12–14.
- Song M, Park H, Lee K. Development of mobile units and integrated system for emergency. In: International joint conference on SICE-ICASE, Bexco, Busan, Korea, 18–21 Oct. 2006, p. 1131–1134.
- Wang D, Lu Y, Zhang H, Zhang J, Han Y: Body Piconet for the telemedicine system based on home networks. In: IEEE/ICME international conference on complex medical engineering, 2007, p. 1202–1205.
- Zheng Y-L, Ding X-R, Poon CCY, Lo BBL, Zhang H, Zhao N, Zhang Y-T. Unobtrusive sensing and wearable devices for health informatics. *IEEE Trans Biomed Eng.* 2014;61(5):1538–54.
- Rangayyan R. Biomedical signal analysis-a case study approach. Wiley India ed; 2013. ISBN 978-81-265-2219-4.
- American Heart Association AHA – Committee on Electrocardiography. Recommendations for standardization of instruments in electrocardiography and vector cardiography. *IEEE Trans BME.* 1967;14:60–8.
- Kohler BU, Hennig C, Orglmeister R. The principles of software QRS detection. *IEEE Eng Med Biol Mag.* 2002;21(1):42–57.
- Pandya UT, Desai UB. Feasibility study of filtering algorithm for low cost wireless physiological monitoring system. In: 2nd international conference on wireless communications, vehicular technology, information theory and aerospace & electronics systems, Feb 28–Mar. 3, 2011.
- Kang WS, Yun S, Cho K. ECG denoise method based on wavelet function learning. In: Proceedings of IEEE Sensors, Oct. 2012, p. 1–3.
- Saponara S, Donati M, Bacchillone T, Fanucci L, Sanchez-Tato I, Carmona C, Barba P. Remote monitoring of vital signs in patients with chronic heart failure: Sensor devices and data analysis perspective. In: Proceedings of IEEE sensors applications symposium, 2012, p. 1–6.
- Wcislik M, Pozoga M, Smerdzynski P. Wireless health monitoring system. In: Elsevier, science Direct, IFAC international federation of automatic control. Paper online 48-4, 2015, p. 312–317.
- Li J, Deng G, Wei W, Wang H, Ming Z. Design of a real-time ECG filter for portable mobile medical systems. *IEEE Access.* 2017;5:696–704.
- Bortolan G, Christov I, Simova I, Dotsinsky I. Noise processing in exercise ECG stress test for the analysis and the clinical characterization of QRS and T wave alternans. *Biomed Signal Process Control.* 2015;18:378–85.
- Ko BH, Lee T, Choi C, Kim YH, Park G, Kang K, Bae SK, Shin K. Motion artifact reduction in electrocardiogram using adaptive filtering based on half cell potential monitoring. In: Proceedings of 2012 annual international conference of the IEEE engineering in medicine and biology society, 2012, p. 1590–1593.
- Lin CT, Chang KC, Lin CL, Chiang CC, Lu SW, Chang SS, Lin BS, Liang HY, Chen RJ, Lee YT, Ko LW. An intelligent telecardiology system using a wearable and wireless ECG to detect atrial fibrillation. *IEEE Trans Inf Technol Biomed.* 2010;14(3):726–33.
- Luo Y, Hargraves RH, Belle A et al. A hierarchical method for removal of baseline drift from biomedical signals: application in ECG analysis. *Sci World J.* 2013. <https://doi.org/10.1155/2013/896056>.
- Pandya UT, Desai UB, Marchant SN. Realization of Bluetooth Piconet for real time monitoring of multiple parameters. *Biomed Eng Lett.* 2013;3(2):95–101.
- Pandya UT, Desai UB. A novel algorithm for bluetooth ECG. *IEEE Trans Biomed Eng.* 2012;59(11):3148–54.
- <http://www.bluesoleil.com/products.html>. Accessed 21 Nov 2017.
- Ostertagova E, Ostertag O. Methodology and application of Savitzky-Golay moving average polynomial smoother. *Glob J Pure Appl Math.* 2016;12(4):3201–10.
- <http://www.mathworks.nl/access/helpdesk/help/toolbox/signal/sgolay.html>. Accessed 10 Jan 2017.