Real Time Heart Rate Detection from PPG Signal in Noisy Environment

Sangita Das*, Saurabh Pal, Madhuchhanda Mitra
Department of Applied Physics, University of Calcutta, 92 A.P.C Road, Kolkata (W.B), India
Email ID: babiinst@gmail.com

***Abstract*— In this paper a Photoplethysmography (PPG) based noise robust real time heart rate measurement technique is proposed. It has been developed using Arduino Uno board based on 8-bit AVR core microcontroller and having 16 MHz clock frequency. The basic idea of the proposed work is to extract the periodic PPG signal contaminated by non-periodic noise and atrifact. The algorithm is based on short term autocorrelation technique over the time shifted PPG signal. The algorithm and the developed system is validated against the heart rates derived from the signals acquired in BIOPAC MP150 data acquisition system. The designed system is highly noise robust and it can detect heart rate with almost 0% error considering BIOPAC MP150 as a standard.**

Keywords—heart rate; real-time system; Arduino; PPG signal

I. INTRODUCTION

Heart rate monitoring during pathological conditions and physical excrcise is very important. It is also essestial to monitor heart rate regularly for early diagnosis of any kind of developing cardiac diseases. Heart rate can be easily detected from Photoplethysmography signal because it provides accurate inter pulse intervals. Photoplethysmography (PPG) is a non invasive optical technique for measuring changes in the volume of blood in the blood capillaries by illuminating the skin by an infrared light source and measuring the variations in light intensity reflected or passing through the skin tissue by a photodiode [1,2]. A typical PPG pulse is shown in Fig. 1. It consists of two sections, anacrotic phase and catacrotic phase. Anacrotic phase is the rising edge of the pulse during systole and catacrotic phase is the falling edge of the pulse during diastole. A dicrotic notch can be found in the PPG pulse of a subject with healthy complitant arteries in the catacrotic phase. The distance between to consecutive systolic peak is referred to as peak to peak interval as shown in Fig. 1. The ECG R-R interval correlates closely with PPG peak to peak interval and both represents a complete cardiac cycle. So the peak to peak interval has been used to detect heart rate from PPG signal. However motion arifacts contaminates the PPG signal during physical training and interferes with heart rate estimation. The motion artifacts genenerates mainly due to ambient light leaking between the gap of skin surface and sensor surface and also for the change in blood flow due to movement [3]. It contaminates the signal so much that it becomes essential to denoise the signal for extracting useful information from the signal. Mostly the frequency of the noise signal lies with in the limit of the frequency band of the desired PPG signal. For this reason sometimes it becomes difficult to denoise the signal with linear filtering techniques.

Various algorithms are proposed to reduce motion artifact from the PPG signal in the presence of moderate motion so far [4-7]. The techniques are basically based on wavelet denosing [8], kalman filtering [9], empirical mode decomposition[10] etc. An adaptive and real time digital filtering technique is used to distinguish heart rate and respiration rate from PPG signal [11]. In this technique respiration rate is detected using peak intervel and heart rate is determined using zero crossing method. In another work a fuzzy logic discriminator has been used to extract the heart rate from a noisy PPG signal [12]. Another heuristic algorithm of heart rate detection from PPG signal in presence of severe motion artifact is proposed which is based on linear filtering and frequency domain analysis [13]. The result is validated using a reference ECG based measurement. A new method is described in [14] to reduce the artifact corruption of the PPG signal in real time by implementing an inversion of a physical artifact model using an electronic processing methodology. In a recent work both heart rate and respiratory rate is estimated using empirical mode decomposition (EMD) from PPG signal [18]. In another work heart rate monitoring is done from wrist-type photoplethysmographic signal contaminated by extremely strong motion artifacts caused by hand movement of the subject [19].

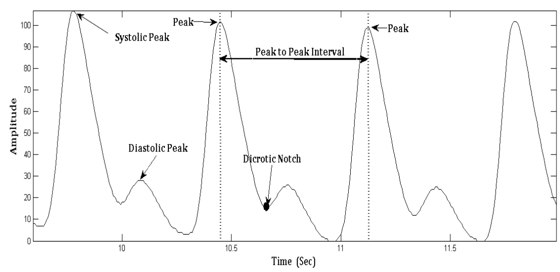

Fig. 1. A typical PPG waveform

Most of the transform based methods are impractical to implement by a hardware in respect of time and memory space for real time applications. The linear filtering techniques are some time not capable of efficiently denoising the signal. Our proposed algorithm has its own noise supression capability without using any filtering technique. The algorithm is autocorrelation based and it is basically used to extract the period of a periodic signal by automatocally supressing the aperiodic component. Most of the undesired noise has its inherent aperiodicity, so it get cancelled automatically. To develop the heart rate detection system, a data acquisition system has been developed to acquire PPG data from human subject. The DAQ system fed the acquired data to the Arduino based system which works with a great efficiency to detect heart rate from motion artifact contaminated PPG signal.

II. Materials and Methods

Ten healthy volunteers(M/F: 6/4) were participated in this research work. A consent from was filluped by the participents prior to the acquisition of the PPG signal. The volunteers were explained how the data will be used and assured to keep their personal information confidential. PPG signal was acquired in sitting position from their right index finger. Both clean and noisy data have been acquired from the subjects to validate the algorithm. The subjects were asked to stay calm and breath spontaneously when acquiring clean data. To create noisy database contaminated by motion artifact the volunteers were asked to move their finger gently. The aquired analog PPG signal can be directly fed to the analog input channel (it has 6 analog input channels) of the Arduino Uno board after using proper signal conditioning circuit, provided the input signal must be in the range of (0-5) V. BIOPAC MP150 system is used to validate the heart rate detection system.

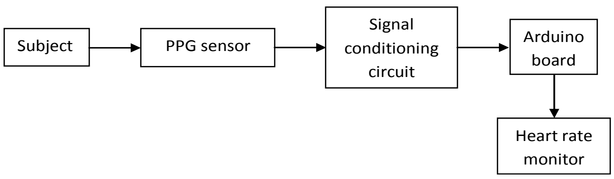

Fig. 2. Block diagram of the online heart rate detection system.

Fig. 2 shows the block diagram of the system. The PPG signal is aquired from the subject using TCRT 1000 which can detect the presence of an object by emitting a IR light and by detecting the IR beam from the object. The output of the PPG sensor is fed to the signal conditioning block. A high pass filter with cut off frequency 0.07 Hz. After that a lowpass filter with cut off frequency 33 Hz is used to eliminate high frequency noises. A final gain amplifier is used to pull up the signal at the desired value. Then a dc level shifter is used to eliminate the negative portion of the signal. The final output of the signal conditioner block is in the range (0-5) volt.

A. Programming algorithm

For the implementaion of the heart rate detection algorithm we use Arduino uno board which is a microcontroller board based on the ATmega328P. The board has an 8-bit AVR processor and the operating clock frequency is 16 MHz. It has its own analog input channel (6 channels). Direct analog pin PPG signal is sampled at 250Hz sampling rate. Four hundred samples are taken at a time to make a complete data frame. One frame of data comprises minimum two or maximum three PPG signal peaks. The sampled data has 10 bit quantization by default which is (0-1024). The data is scaled to 8 bit signed number (-127 to +128). For this scaling process the data is first converted to (0-255) and then the mean value is subtracted from each data to form mean zero data frame. Now the period of the quasi periodic PPG signal is determined using autocorrelation algorithm as explain below.

B. Heart rate detection algorithm

The short term autocorrelation is applied on the data frame and the peak of the autocorrelation function is determined for calculating the period of the function which is equal to the period of the PPG signal. The first peak of autocorrelation function is the peak due to the fundamental frequency of the PPG signal. So the distance (sample points) of that peak from the origin is used to calculate the period of the signal and from that, heart rate can be easily determined using the fundamental equation of heart beat rate. The autocorrelation function is defined as

$$y(m) = \sum_{n=1}^{N} X(n)X(n+m) \tag{1}$$

Where N is the total number of sample points in the data frame and m varies from zero to (N-1). The heart beat rate per minute is defined as,
HBR=60 second / occurrence time for one beat
HBR= (60*sampling rate of the signal) / number of samples

$$HBR = \frac{60 * F_s}{N_s} \tag{2}$$

Where F_s is the sampling frequency and N_s is the index point corresponding to the peak location. The minimum and maximum heart rate is taken as 50 bpm and 120 bpm [20] because normal human heart rate always lies between this range. For the above specified heart rate range (50-120 bpm) the maximum (Nmax) and minimum (Nmin) sample index are calculated from the equation of heart beat rate as, $N_{min} = \frac{60F_s}{120}$ and $N_{max} = \frac{60F_s}{50}$, where Fs is the sampling rate which is 250 Hz. Now the peak is searched within the data frame $(N_{min} - 10)$ to $(N_{max} + 10)$ i.e. from 115 sample index to 310 sample index. This extra 10 sampling point before Nmin and after Nmax is used to definitely include the boundary points in the searching window. After finding the first peak location of the autocorrelation function the distance (number of sample points) of the peak location from the origin is determined and from that the heart rate is determined using (2). If no peak is found within the specified data frame it means the heart rate is beyond the limiting value (50-120 bpm). In this case a warning message is displayed and the process is continued for next data frame. Flow chart of the proposed heart rate detection algorithm is shown in Fig. 3.

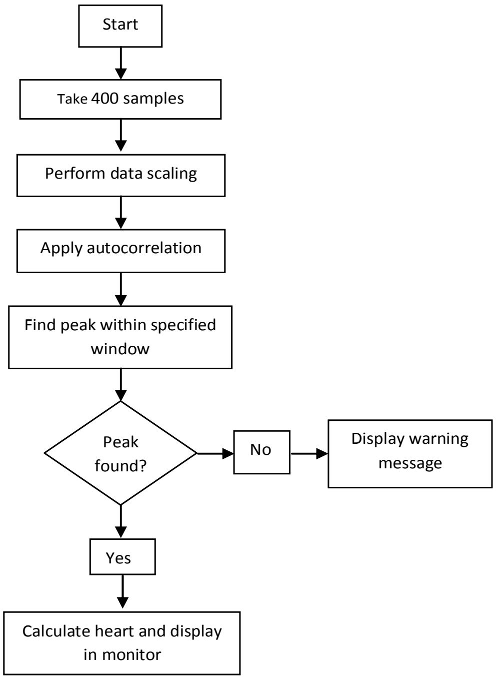

Fig. 3. PPG wave form and its autocorrelation function showing the peak for heart rate detection using MATLAB.

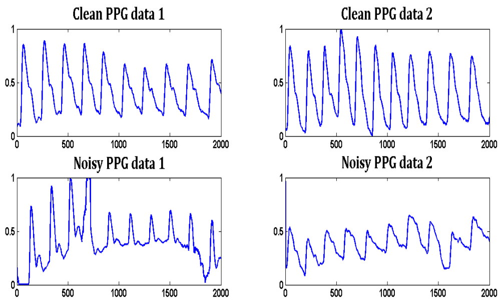

Fig. 4. PPG data (clean and noisy) acquired at laboratory using PPG signal acquisition system.

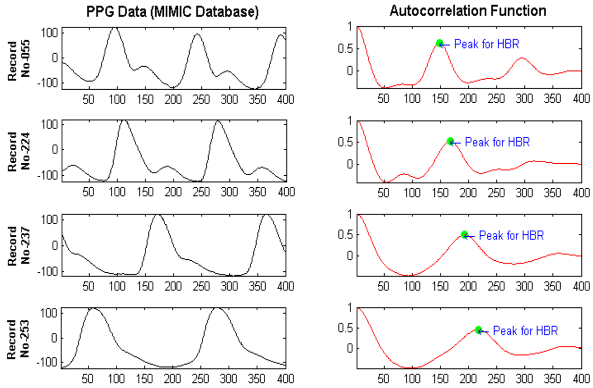

Fig. 5. PPG wave form and its autocorrelation function showing the peak for heart rate detection for MIMIC database using MATLAB.

III. Results And Discussions

The proposed system is validated using BIOPAC MP150 system in our laboratory. By the comparison we can see that the system is capable of detecting heart rate with almost zero percentage error. In case of motion artifact contaminated PPG signal the algorithm is equally useful because of its own noise resistive capability. As PPG is a quasi periodic signal, the essence of the algorithm is basically to determine the period of a periodic signal and to suppress the aperiodic components i.e. noise. As a short length of data frame of 400 data is used the heart rate calculated from the average period of the signal is nearly equal to the instantaneous heart rate. Table 1 shows the comparative study of the performance between the proposed heart rate detection system and the BIOPAC MP150 system. The programming algorithm takes only twenty millisecond to execute the heart rate detection algorithm. As the data sampling rate is 250 Hz, only five data is missed at the time of execution of the program which has no impact on the measured heart rate. So this is a real-time system. Both clean and noisy PPG signal are used to evaluate the performance of the system. Motion artifact is incorporated to create noisy PPG signal by moving the finger gently when PPG data was acquired from a subject. Fig. 4 shows clean and noisy data acquired at the laboratory using the developed data acquisition system. The algorithm is tested using 35 standard data of MIMIC data base downloaded from physionet.org [21, 22]. Fig. 5 shows the PPG waveform and its corresponding autocorrelation function for four PPG record from MIMIC database. Fig. 6 shows PPG waveform and its corresponding autocorrelation function indicating the peak for heart rate detection for noisy laboratory data.

TABLE I. Evaluation and comparison of the system with BIOPAC system (standard system)

Signal type	Subject No.	Gender	Heart rate detected by the arduino based system in **bpm** (hr1)	Heart rate measured by BIOPAC system in **bpm** (hr2)	% error = $\left(\frac{hr2-hr1}{hr1}\right)$
Clean	1	M	73	73	0
	2	F	72	72	0
	3	M	81	81	0
	4	M	92	92	0
	5	F	75	75	0
Noisy	6	M	91	91	0
	7	F	69	69	0
	8	M	85	85	0
	9	F	72	72	0
	10	M	88	88	0

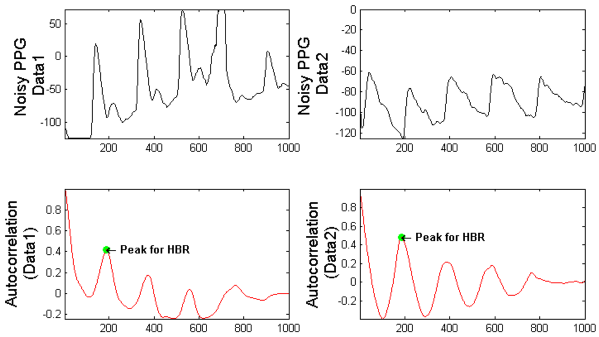

Fig. 6. PPG wave form and its autocorrelation function showing the peak for heart rate detection for noisy PPG data.

IV. Conclusion

PPG is a low cost non invasive optical technique. PPG signal is very easy to acquire and it provides accurate inter pulse intervals. Though it comprises great clinical significance, the data acquisition circuit requires minimum circuit components and the signal conditioning circuit is also very simple due to the inherent simplicity of the PPG signal pattern. So determining heart rate from PPG is advantageous. Here the algorithm used is very simple and it provides excellent result (almost 0% error) when compared with a standard system even in the presence of severe motion artifacts. The algorithm is easily implemented to develop the automatic online heart rate detection system using Arduino. So the system can be used as a standalone real time heart rate detection system in noisy environment.

References

[1] A. B. Hertzman, and C. R. Spealman, "Observations on the finger volume pulse recorded photoelectrically," Am. J. Physiol, vol. 119, no. 334, pp. 3, 1937.

[2] A. B. Hertzman, "Photoelectric plethysmography of the fingers and toes in man," Experimental Biology and Medicine, vol. 37, no. 3, pp. 529-534, 1937.

[3] Maeda, Yuka, M. Sekine, and T. Tamura, "Relationship between measurement site and motion artifacts in wearable reflected photoplethysmography," Journal of medical systems, vol. 35, no. 5, pp. 969-976, 2011.

[4] Townshend, Jennifer, B. J. Taylor, B. Galland, and S. Williams, "Comparison of new generation motion-resistant pulse oximeters," Journal of paediatrics and child health, vol. 42, no. 6, pp. 359-365, 2006.

[5] Kim, S. Byung, and S. K. Yoo, "Motion artifact reduction in photoplethysmography using independent component analysis," IEEE transactions on biomedical engineering, vol. 53, no. 3, pp. 566-568, 2006

[6] Yan, Y. sheng, C. CY Poon, and Y. Zhang, "Reduction of motion artifact in pulse oximetry by smoothed pseudo Wigner-Ville distribution," Journal of NeuroEngineering and Rehabilitation, vol. 2, no. 1, pp. 1, 2005.

[7] Z. Zhang, "Photoplethysmography-based heart rate monitoring in physical activities via joint sparse spectrum reconstruction," IEEE Transactions on Biomedical Engineering, vol. 62, no. 8, pp. 1902-1910, 2015.

[8] Raghuram, M. K. Venu Madhav, E. H. Krishna, and K. A. Reddy, "Evaluation of wavelets for reduction of motion artifacts in photoplethysmographic signals," In Information Sciences Signal Processing and their Applications (ISSPA), 2010 10th International Conference on, pp. 460-463, IEEE, 2010.

[9] Lee, Boreom, J. Han, H. J. Baek, J. H. Shin, K. S. Park, and W. J. Yi, "Improved elimination of motion artifacts from a photoplethysmographic signal using a Kalman smoother with simultaneous accelerometry," Physiological measurement, vol. 31, no. 12, pp. 1585, 2010.

[10] Sun, Xuxue, P. Yang, Y. Li, Z. Gao, and Y. T. Zhang, "Robust heart beat detection from photoplethysmography interlaced with motion artifacts based on empirical mode decomposition," In Proceedings of 2012 IEEE-EMBS International Conference on Biomedical and Health Informatics, pp. 775-778, IEEE, 2012.

[11] Nakajima, K. T. Tamura, and H. Miike, "Monitoring of heart and respiratory rates by photoplethysmography using a digital filtering technique," Medical engineering & physics, vol. 18, no. 5, pp. 365-372, 1996.

[12] Liu, S. Hong, K. M. Chang, and T. Fu, "Heart rate extraction from photoplethysmogram on fuzzy logic discriminator," Engineering Applications of Artificial Intelligence, vol.23, no. 6, pp. 968-977, 2010.

[13] L. Silva, S. María, R. Giannetti, M. L. Dotor, J. P. Silveira, D. Golmayo, F. M. Tobal, A. B. Monasterio, M. G. Canales, and P. M. Escudero. "Heuristic algorithm for photoplethysmographic heart rate tracking during maximal exercise test." (2012).

[14] Hayes, M. James and P. R. Smith, "A new method for pulse oximetry possessing inherent insensitivity to artifact," IEEE Transactions on Biomedical Engineering, vol.48, no. 4, pp. 452-461, 2001.

[15] Nitzan, Meir, A. Babchenko, B. Khanokh, and D. Landau, "The variability of the photoplethysmographic signal-a potential method for the evaluation of the autonomic nervous system," Physiological measurement, vol. 19, no. 1, pp.9, 1998.

[16] Charlot, K. J. Cornolo, J. V. Brugniaux, J. P. Richalet, and A. Pichon, "Interchangeability between heart rate and photoplethysmography variabilities during sympathetic stimulations," Physiological measurement, vol. 30, no. 12, pp. 1357, 2009.

[17] K. H. Shelley, "Photoplethysmography: beyond the calculation of arterial oxygen saturation and heart rate," Anesthesia & Analgesia, vol.105, no. 6, pp. S31-S36, 2007.

[18] A. Garde, W. Karlen, P. Dehkordi, J. M. Ansermino, and G. A. Dumont, "Empirical mode decomposition for respiratory and heart rate estimation from the photoplethysmogram," In Computing in Cardiology 2013, pp. 799-802, IEEE, 2013.

[19] Zhang, Z. P. Zhilin, and B. Liu, "TROIKA: A general framework for heart rate monitoring using wrist-type photoplethysmographic signals during intensive physical exercise," IEEE Transactions on Biomedical Engineering vol. 62, no. 2, pp. 522-531, 2015.

[20] Khandpur, and R. Singh, Handbook of biomedical instrumentation. Tata McGraw-Hill Education, 1992.

[21] G. B. Moody, and R. G. Mark, "A database to support development and evaluation of intelligent intensive care monitoring," In Computers in Cardiology, pp. 657-660, IEEE, 1996.

[22] Goldberger, L. Ary, L. A. Amaral, L. Glass, J. M. Hausdorff, P. Ch Ivanov, R. G. Mark, J. E. Mietus, G. B. Moody, C. Peng, and H. E. Stanley. "Physiobank, physiotoolkit, and physionet components of a new research resource for complex physiologic signals," Circulation, vol. 101, no. 23, pp. e215-e220, 2000.