Wireless System for Measurements of RR Variability During Physical Activity

A Patil, R Chile, S Hamde

Citation

A Patil, R Chile, S Hamde. *Wireless System for Measurements of RR Variability During Physical Activity*. The Internet Journal of Bioengineering. 2008 Volume 3 Number 2.

Abstract

RR variability is one of the very important tools today for understanding the cardiac activity under dynamic conditions. Acquiring the heart rate data under dynamic conditions is very difficult task. ECG recording is exposed to many technical and physiological disturbances, which are not easily prevented or controlled. Considering this, a wireless system has been developed to acquire RR intervals from the subject using cardiosport transmitter and cardiopulse receiver. A digital signal processing software DADiSP has been used to analyze various parameters of the RR series. The heart rate monitor belt transmits 5 KHz pulse for each 'R' wave that lasts for about 35 milliseconds. The receiver has heart-rate sensor and four-stage amplifier with active band pass filters. A sharp positive pulse is obtained for each 'R' wave and fed to the computer. The system is flexible. Data can be collected while the subject is at rest or doing exercise.

INTRODUCTION

The RR variability (RRV) or Heart rate variability (HRV) is a non-invasive index of the neural control of the heart. It can be quantified by the simple calculation of the standard deviation of the RR intervals. The last three decades have witnessed the recognition of a significant relationship between the autonomic nervous system and cardiovascular mortality, including sudden cardiac death. Experimental evidence for an association between propensity for lethal arrhythmias and signs of either increased sympathetic or reduced vagal activity has spurred efforts for the development of quantitative markers of autonomic activity (Task Force, 1996). Heart rate variability (HRV) represents one of the most promising such markers. There is an increasing need for the development of sensitive tools for risk factor stratification because of the danger of cardiac arrhythmias and sudden cardiac death. It is important to identify in what populations these risks are most prominent or pose a great amount of caution. The most crucial application of HRV measurement is in its prognostic indication for sudden cardiac death. Therefore, developing the most appropriate tools for analysis of HRV is important for risk stratification. Determining risk of cardiac events is an asset in treatment and management of disease.

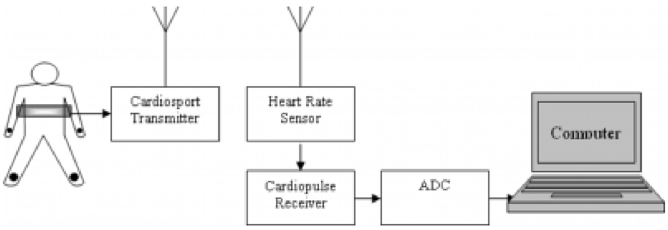
In HRV analysis either the heart rate as a function of time or intervals between successive QRS complexes need to be determined. There are two methods of analysis of HRV data: time and frequency-domain analysis. In either method, the interbeat intervals should be properly calculated and all abnormal heartbeats and artifacts must be removed from consideration. Time-domain measures are the simplest parameters to be calculated. The following time-domain parameters can be calculated for short-term recordings: Mean HR, SDNN and RMS-SD. The time-domain parameters are associated mostly with the overall variability of the HR over the time of recording, except RMS-SD, which is associated with fast (parasympathetic) variability. Furthermore, in the frequency domain, spectral analysis of HRV reveals three distinct frequency regions in the modulation of heart rate in humans. The typical spectral pattern, in normal conditions shows the presence of three frequency bands: a very low frequency (VLF) band from 0.00 to 0.04 Hz, a low frequency (LF) band from 0.04 to 0.15 Hz and a high frequency (HF) band of more than 0.15 Hz. LF component increases with every form of sympathetic stimulation, whereas the area of high frequency component (HF) provides a quantitative index of the influence of respiration on heart rate signal and may be connected to the vagal activity. Thus LF/HF ratio is an important marker of sympathetic modulation or sympatho-vagal balance on heart rate variability control.

MATERIALS AND METHOD

The purpose of this work was to design and develop wireless system for measurement of heart rate variability. The system consists of cardiosport transmitter belt, heart rate sensor, cardiopulse receiver, parallel port ADC and Digital Signal Processing software. The system is shown in fig.1.

Figure 1

Figure 1: Wireless System for Study of RR Variability



The heart rate monitor belt transmits 5 KHz pulse for each ‘R' wave that lasts for about 35 milliseconds. The 35mS cardiosport pulse (amplified) is shown in fig.2. The pulse is generated at the peak of ECG ‘QRS' complex. The receiver has heart rate sensor, four-stage amplifier with active band pass filters, comparator, refractory generator, standard pulse generator, differentiator, and ADC card. The hard ware is realized around quad operational amplifier TL074, multivibrator LM4538 and Picotech ADC card. The circuit is biased from 5 volts power supply. The heart rate sensor is a pick-up coil of cardiopulse receiver that produces a signal of 100-500 V amplitude. This signal is produced, when it is placed around the transmitter, in the range of about one meter. To take care of electrical interference from other electronic devices, lower and upper cutoff frequencies of the receiver are kept at 3KHz and 7KHz respectively. The receiver has fixed gain of 10000. Output of amplifier and filter stage-II is shown in fig.3. Signal is then processed to produce a sharp positive pulse that represents each ‘R' wave using comparator, standard pulse generator and differentiator. Standard pulses that represent each heartbeat are fed to the LED flasher to have indication of generated heart beat. The train of processed pulses is shown in fig.4. This train of pulses is then fed to the computer through parallel port ADC (Picotech) and monitored using Picoscope software. The Digital signal processing software DADiSP is employed to process acquired signal.

Figure 2

Figure 2: Transmitter Pulse

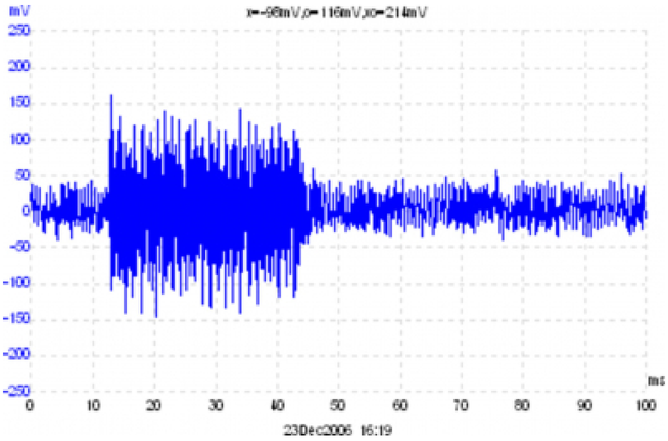


Figure 3

Figure 3: Output of amplifier and filter stage-II

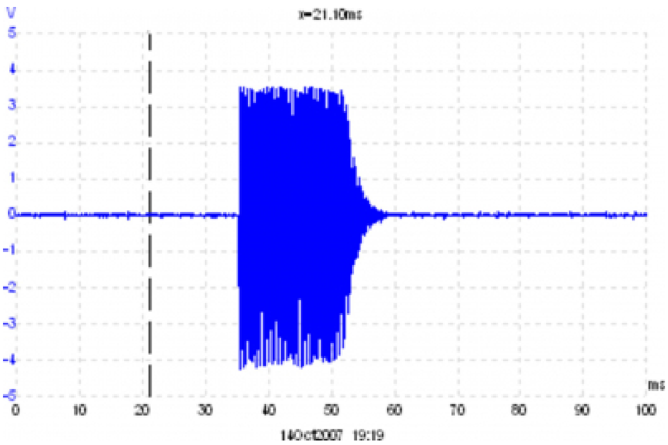
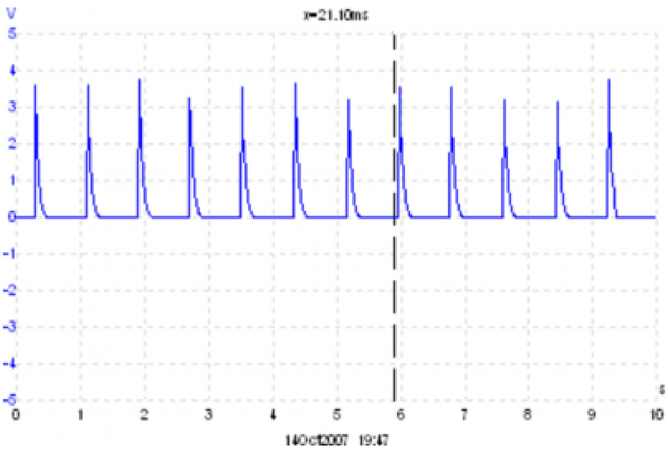


Figure 4

Figure 4: Output of Cardiopulse Receiver



The flow chart summarizing individual steps used when recording and processing RR intervals in order to obtain data for RRV analysis is shown in fig.5. RR wave-pulses received through ADC card and processor are monitored using Pico-oscilloscope. Acquired signal is checked properly for noise and artifacts if any. If necessary, the procedure is repeated to have noise free data from the subject. Such instances were very rare and discharged battery or noisy electrical appliances around the subject mainly caused that. This data is then copied to the first window of DADiSP worksheet. At this stage, signal is processed step by step in the worksheet.

Initially, 128 seconds series of RR waves is extracted into another window (fig.6). Using get-peak function, peaks of RR waves are detected and plotted as shown in fig.7. Threshold for get-peak function is set by visual inspection of peaks so as to have selection of all peaks that represent 'R' waves. Optimum care has been taken while inspecting data at this stage, as improper selection of artifact, ectopic or noise pulses would result in wrong index value. However, no editing is necessary in 99 % cases, as pulses are sharp and have large amplitudes. RR intervals are plotted in next window by taking derivative of these peaks (fig.8). Accuracy of one millisecond was maintained during this process. RR interval time series is an irregularly time-sampled series and should therefore be interpolated prior to spectrum estimation. Hence, it is interpolated by two and processed for PSD. Related worksheet windows are shown as fig.9 and fig.10. It calculates, Mean-RR and SD-RR in time domain, whereas, VLF, LF, HF, TF and LF/HF parameters in frequency domain.

Figure 5

Figure 5: Flow chart summarizing individual steps used when recording and processing RR Intervals in order to obtain data for RRV analysis.

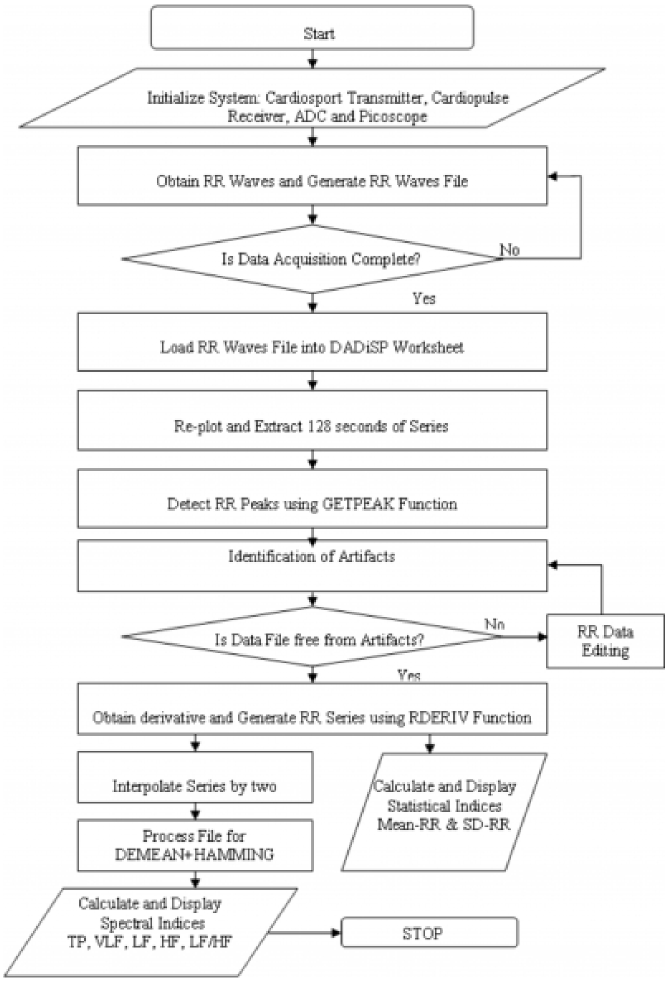


Figure 6

Figure 6: R Waves

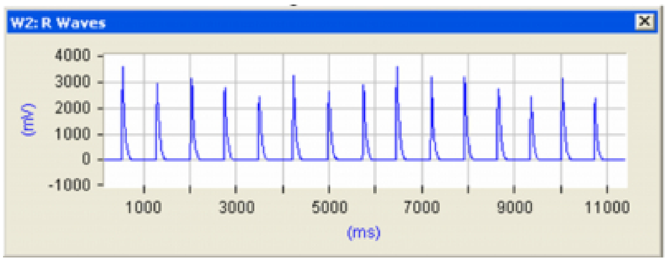


Figure 7

Figure 7: R Wave Peaks

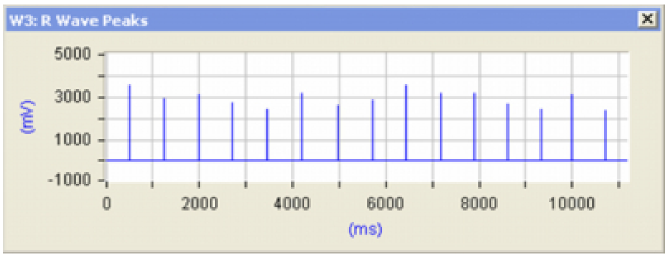
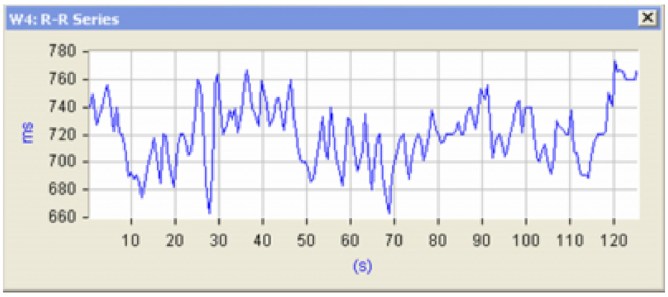


Figure 8

Figure 8: RR Series



To determine values for RR variability, we recruited a sample of 15 healthy persons 17 to 50 years old. In this study, RR intervals were recorded in three different modes or positions: supine, sitting and five seconds rhythm respiration or deep respiration. At a time 150 seconds R-R interval data was acquired in each mode. All experiments were performed in the afternoon between 2.00pm to 7.00pm, at least 2 hours after a lunch in a quiet environmentally controlled recording room. The subjects were asked to refrain from heavy exercise or alcoholic beverages and smoking for at least 24 hours before the tests. On entering the recording room, each participant was transferred onto a table and fitted with a Cardiosport belt sensor. In an attempt to achieve steady-state resting conditions, participants lay quietly in a dark, quiet room for 10 min before the start of data collection. The testing protocol consisted of a 10-minutes period of supine rest, a 2.5 minutes supine-mode recording, a 2.5-minutes sitting-mode recording, a 10 minutes supine rest and 2.5 minutes deep breathing or rhythm respiration recording.

Figure 9

Figure 9: Power Spectral Density

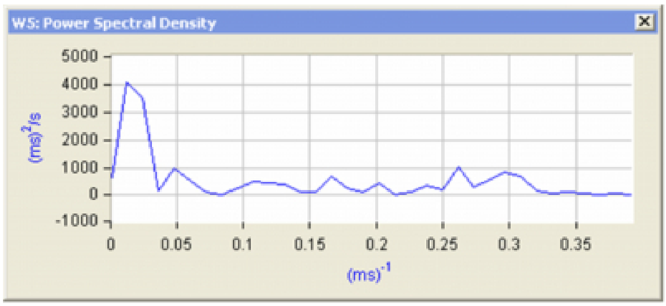


Figure 10

Figure 10: Statistical and Spectral Values

(SUG, Female, Age 31, Deep Breathing)

W5: Statistical and Spectral Values

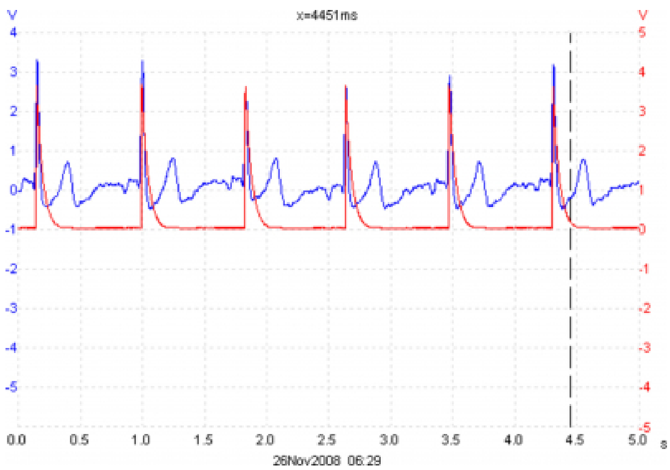
	1: Mean HR	2: STD-HR	3: Mean RR	4: STD-RR	5: VLF	6: LF	7: HF	8: Total Power	9: LF/HF
1:	83.35	2.65	720.55	22.89	96.97	42.77	71.74	123.01	0.60

RESULTS AND DISCUSSION

The system was initially tested on number of subjects to analyze its performance and assess its suitability for research. Accuracy of wireless system was compared with ECG system. This was done by recording ECG and output of cardiopulse receiver simultaneously, from same subject using two-channel Picotech ADC card (ADC100). Recordings are shown in fig.11.

Figure 11

Figure 11: Comparison between Recording using ECG and Wireless System



It was observed that results obtained by developed system are cent-to-cent percent comparable with the system using ECG. Results show that wireless system is most appropriate for this type of research. Furthermore, no electrodes need to be connected to the subject to acquire the data. We measured time and frequency domain based indices for 15 subjects.

Results obtained are comparable with existing HRV analysis systems. The mean results obtained are shown in Table 1.

Figure 12

Table 1: RRV Measurements on Normal Subjects

MODE	MEAN RR (s)	SD-RR (s)	TF (ms^2)	VLF (ms^2)	LF (ms^2)	HF (ms^2)	LF/HF	Sd (LF/HF)
Supine	0.881	0.05	3818.6	1671.8	1298.06	848.73	1.68	0.46
Sitting	0.823	0.07	12872.4	10004.8	2318.73	548.86	4.86	1.44
Deep Breathing	0.834	0.06	6288.2	1675.93	1115.06	3497.20	0.34	0.11

A cardiosport pulse transmitter belt is probably the easiest way to detect RR-interval times. It is lightweight, waterproof, comfortable, and accurate. The developed receiver has optimum performance to acquire RR series signals from the subject in the range of about one meter. The system is flexible; data can be collected while the subject is at rest or doing exercise. The system is capable of analyzing ECG signal to get: Mean-RR, SD-RR, VLF, LF, HF, Total Power and ratio LF/HF values.

References

1. Marek Malik, "Heart Rate Variability" Standards of Measurement, Physiological Interpretation, and Clinical Use, Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, Circulation. 1996;93:1043-1065
2. P.B. Siegela, J. Sperberb, A. Urhausenb, W. Kindermannb, "Putting your Heart into Physics", a Physics Department, California State Polytechnic University Pomona, Pomona, Calif.; bInstitute for Sport and Preventative Medicine, University of Saarland, Saarbruecken, Germany
3. A.G. Patil, R.H.Chile, S.T. Hamde, 'System for study and analysis of R-R time series signal in spinal cord injury patients', Proceedings of BIOCON-2005-National Conference on Emerging Trends in Biomedical Engineering, 15-16 September. 2005,Pune, India
4. Vadim Pougatchev MD, Eugene Zhirnov MD, Eugene Gribkov MD, 'Short-term HRV Analysis and Assessment of the Autonomic Regulation', MedPond, LLC
5. Danev S., H.Wartna, B.Bink, J.Lutein, J.Rader: 'Assessment of information load', Ned. Tjidshrift foor de Psychology XXI, 1, 1971
6. B. Mac. Sayers, `Analysis of heart rate variability', Ergonomics 16, 17-32, 1973
7. Patil A.G., 'Instrumentation and techniques for rehabilitation of spinal cord injury patients', M.S. Dissertation, 1994
8. E.L.Fallen, D. Nandagopal, S.Connolly and D.N. Ghista, `How reproducible is the power spectrum of heart rate variability in health subjects ?', Proceedings of International Symposium on Neural and Cardiovascular mechanisms, May 1985, Geneva, Italy
9. R.N.Miftakhov and D.L.Wingate, `Mathematical modeling of the enteric nervous network - 4', Analysis of adrenergic transmission', Med. Eng. Phys. Vol.17, 3-10,1995
10. I. Korhonen, J.P. Saul, R. Takalo, V. Turjanmaa, Model-Based Analysis of Heart Rate and Blood Pressure Variability, 32nd Scandinavian Congress of Neurology & 1 st Scandinavian Congress of Neurological Nursing, Oulu, Finland, June 10-13, 1998
11. William H. Cooke, Jeffrey B. Hoag, Alexandra A. Crossman, Tom A. Kuusela, Kari U. O. Tahvanainen and Dwain L. Eckberg, 'Human responses to upright tilt: a window on central autonomic integration', The Journal of Physiology (1999), 517.2, pp. 617-628
12. J. M. Legramante, G. Raimondi, M. Massaro, and F. Iellamo, 'Positive and Negative Feedback Mechanisms in the Neural Regulation of Cardiovascular Function in Healthy and Spinal Cord-Injured Humans', Circulation, March 6, 2001; 103(9): 1250 - 1255.
13. Joseph Keul, Schmidt-Trucksäss, Daniel König, Dominik Grathwohl, Manfred Lehmann and Andreas Schmid, Martin Huonker, Jose-Miguel Barturen, Fabian Stahl, Arno, 'Catecholamines, heart rate, and oxygen uptake during exercise in persons with spinal cord injury', Journal of Applied Physiology, 85:635-641, 1998.
14. J Koh, TE Brown, LA Beightol, CY Ha, and DL Eckberg, 'Human autonomic rhythms: vagal cardiac mechanisms in tetraplegic subjects', J Physiol (Lond) 1994 474: 483-495
15. Jon N. Myers, PhD; K Gladysheva, BA; Heather E. Brown, MSPT; Inder Perkash, MD; B. Jenny Kiratli, PhD 'Heart Rate Variability and Physical Activity Level after Spinal Cord Injury', VA Rehabilitation Research and Development Service, project #B2549-R
16. A.G. Patil, R.H.Chile, S.T. Hamde, 'Spinal Cord Injury Alters RR Variability: A Comparative Study Between Normal and Spinal Cord Injured Persons', Proceedings of WACBE World Congress on Bioengineering, 9-13 July 2007, Bangkok, Thailand

Author Information

A.G. Patil, M.S.
Department of Medical Electronics, S.B.M. Polytechnic

R.H. Chile, Ph.D.
Department of Instrumentation Engineering, S.G.G.S.Institute of Engineering & Technology

S.T. Hamde, Ph.D.
Department of Instrumentation Engineering, S.G.G.S.Institute of Engineering & Technology