International Journal of Bioelectromagnetism www.ijbem.org
Vol. 16, No. 2, pp. 32- 35, 2014

A new Index for Evaluating Instantaneous Heart Rate Reconstruction Accuracy

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Abstract. This paper shows a method of evaluating the accuracy of the instantaneous heart rate reconstruction. A general evaluation scheme and a new evaluation index have been proposed and three reconstruction methods, Derivative of Cubic Spline Interpolation (DCSI), Resampled Instantaneous Heart Rate (RIHR) and Spline Smoothed Instantaneous Heart Rate (SIHR), are compared. Computer simulation based on Integrated pulse frequency modulation (IPFM) model with modulating signals having 1/*f* power spectrum characteristics has been carried out for comparison. A new index named the Effective bandwidth showed better performance in the following order, *i.e.* DCSI > SIHR > RIHR. It is also noted that SIHR have less estimation bias compared to DCSI in high frequency region. The method will be useful for precise characterization of the frequency domain characteristics of the heart rate.

Keywords: heart rate variability, instantaneous heart rate, derivative of cubic spline interpolation, bio-signal interpretation, 1/f fluctuations, Integrated pulse frequency modulation

1. Introduction

Spectral characteristics of the heart rate variability (HRV) such as HF, LF or LF/HF have been extensively utilized as non-invasive indices to know the human autonomic activities. In order to estimate the HRV spectral characteristics, the heart rate modulation signal has to be reconstructed from RR pulse occurrence times. The methods for the reconstruction have been empirically chosen by researchers[1]-[3]. This paper proposes a systematic method to evaluate the heart rate reconstruction accuracy and the proposed method has been applied to evaluate some typical reconstruction methods, i.e. Derivative of Cubic Spline Interpolation (DCSI)[4], Resampled Instantaneous Heart Rate (RIHR)[1] and Spline Smoothed Instantaneous Heart Rate (SIHR).

2. Methods

2.1. Data acquisition

Fig 1 shows a general scheme to evaluate the reconstruction accuracy of the heart rate demodulators.Modulation signal with power spectral characteristics is numerically generated and fed into an impulse generator. Typically IPFM model is utilized for the impulse generation. Impulse occurrence time sequence has been generated in this pulse modulating step. Then target demodulating algorithms are utilized to estimate the original modulation signal. Power spectrum of original modulation signals and demodulated signals are compared. The effective bandwidth which gives accurate spectral pattern within the tolerance limit of relative estimation error of is compared to measure the reconstruction accuracy. Three commonly used heart rate reconstruction methods are evaluated, i.e. Derivative of Cubic Spline Interpolation (DCSI)[4], Resampled Instantaneous Heart Rate (RIHR) where the instantaneous heart rate is defined as the inverse of RR intervals during that RR period[1] and evenly resampled afterword. Spline Smoothed Instantaneous Heart Rate (SIHR) which is the spline smoothed un-evenly spaced instantaneous heart rate sequence which is defined as the inverse of RR intervals placed at the RR mid points. Resample rate has been set at 4Hz for all cases.

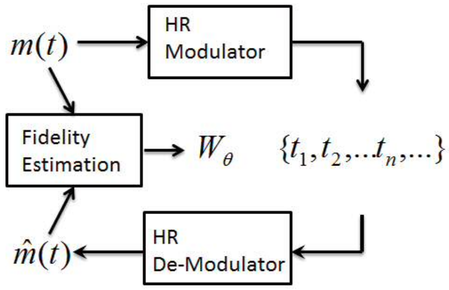

Fig. 1 Evaluating Scheme of the heart rate reconstruction accuracy

Fig. 2 show sample processes of underlying heart rate modulating signal(top trace) with$1/f$ power spectral pattern and demodulated signals by three different methods: DCSI,SIHR, RIHR from the second to bottom traces.

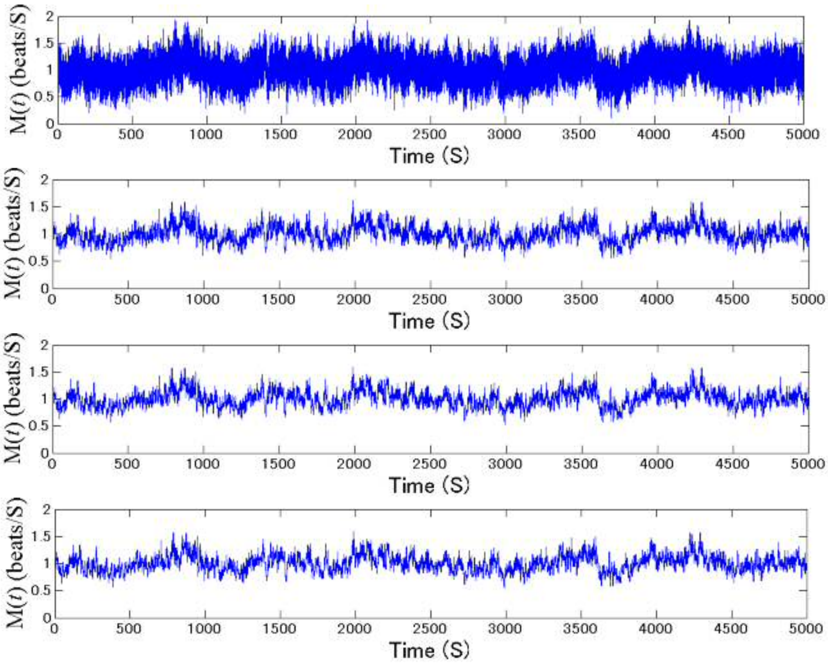

Fig. 2 Sample processes of modulating and demodulated signals

Fig. 3 show examples of estimated power spectra of modulating (top left panel) and demodulated signals(DCSI: top right; SIHR: bottom left; RIHR: bottom right). Straight lines have been fitted to spectra (red lines). It is observed that RIHR starts to fall off at lower frequencies compared to other methods.

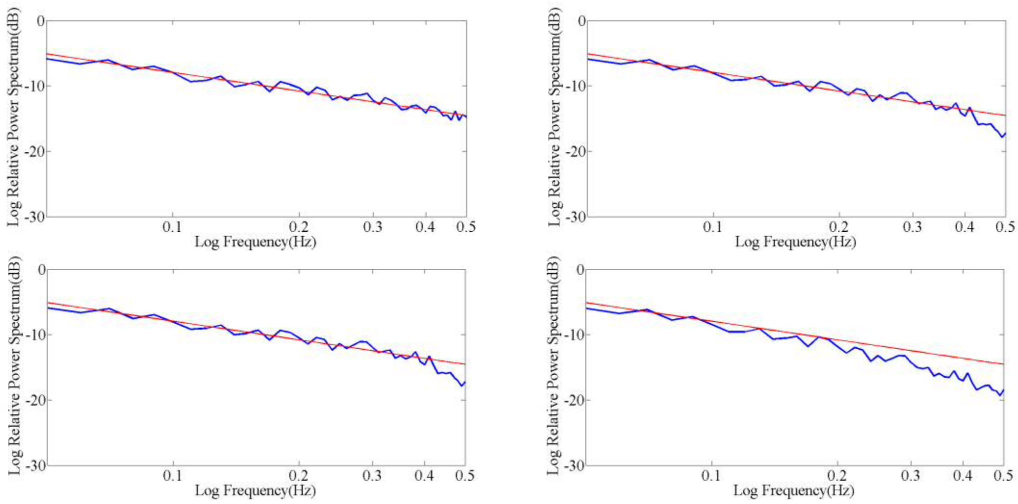

Fig. 3 Estimated power spectra of modulating and demodulated signals

3. Results

The demodulation characteristics of three methods DCSI, RIHR and SIHR are compared. Fig. 4 compare estimated errors of each method when mean heart rate has been changed from 48 to 84 bpm (48: top left; 60: top right; 72: bottom left; 84: right bottom). Horizontal bars show the error range of 10%. DCSI stay accurate up to the highest frequency but has negative bias at the high frequency region, while SIHR shows unbiased estimate to reasonably high frequencies.

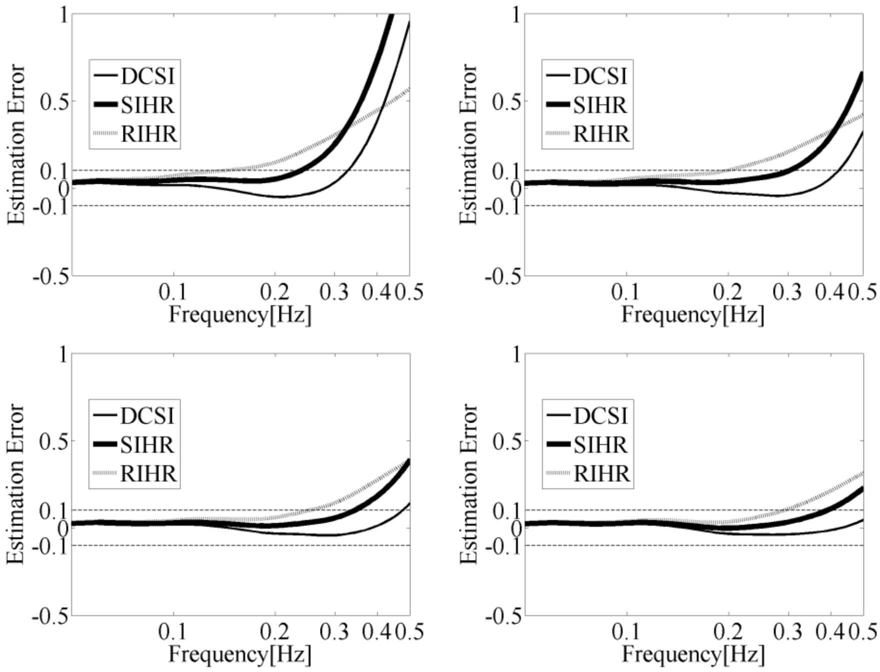

Fig. 4 Demodulation error comparison

Table 1 tabulated ten percent effective bandwidth defined as the frequency range which gives relative errors less than 10percent, in variety of conditions.

Table. 1 Achieved effective bandwidth

C.V.	0.1			
	48[bpm]	60[bpm]	72[bpm]	84[bpm]
DCSI[Hz]	0.34	0.42	0.50	0.57
SIHR[Hz]	0.25	0.30	0.35	0.40
RIHR[Hz]	0.12	0.21	0.25	0.31
C.V.	0.2			
	48[bpm]	60[bpm]	72[bpm]	84[bpm]
DCSI[Hz]	0.33	0.42	0.47	0.54
SIHR[Hz]	0.23	0.29	0.33	0.37
RIHR[Hz]	0.11	0.17	0.23	0.27
C.V.	0.3			
	48[bpm]	60[bpm]	72[bpm]	84[bpm]
DCSI[Hz]	0.31	0.39	0.44	0.50
SIHR[Hz]	0.23	0.28	0.31	0.35
RIHR[Hz]	0.11	0.14	0.23	0.27

The table show that the effective bandwidth of DCSI showed widest in all cases. However DCSI show the negative bias in the 0.2-0.3 Hz range as shown in Fig. 3, which may require error correction in estimating HF power. RIHR effective bandwidths consistently show the narrowest. SIHR showed fairly good unbiased estimate up to reasonably high frequency. In all cases the less coefficient of variation in the modulating signal the better demodulation accuracy.

4. Conclusion

DCSI showed the best demodulation characteristics when the effective bandwidth has been utilized for the index to measure the heart rate reconstruction accuracy. This result is compatible with the result described in [5]. However, DCSI is found to have frequency dependent bias as shown in this paper. Such frequency dependent error characteristics will be important to quantify the estimation bias of the spectral band power. Further comparison with newly proposed method such as [7] will be important for finding the best possible method to quantify the heart rate variability.

Acknowledgements

This work has been supported by the Ministry of Education, Culture, Sports, Science and Technology; MEXT Japan (Grant Number: 24234567).

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