ESTIMATION OF RHYTHMIC VARIATIONS IN R-R INTERVAL DURING SLEEP

°J.M. Han, J.M. Lee, Y.H. Nam, H.J. Park, K.S. Park* and Do-Un Jeong**

Interdisplinary Program, Medical and Biological Engineering Major
*Dept. of Biomedical Engineering , College of Medicine
**Dept. of Psychiatric Science, College of Medicine, Seoul National University, Seoul, Korea

***Abstract*-- Nonlinear energy operator(NEO) is usually used to estimate energy content of linear oscillator. We applied the modified nonlinear energy operator (MNEO) to detect R-peak of ECG and analyzed variation of R-R interval during sleep with nonlinear methods, piecewise correlation dimension and approximate entropy (ApEn) which estimate complexity of time series. ApEn applied to R-R interval reveals trends as sleep state changes.**

INTRODUCTION

In recent years, much research has been done to develop new algorithms for automatic rhythm analysis and characteristic point detection. Several methods have been employed to analyze electrocardiogram (ECG), such as linear prediction, wavelet transform, and so on.

In this paper, a modified nonlinear energy operator (MNEO)[1] is used to detect R peaks in ECG and some nonlinear methods are applied to sequences of the R-R interval in order to estimate changes of sleep states.

The R peak detection algorithm is evaluated using a standard ECG waveforms, MIT-BIH arrhythmia database and applied to real ECG waveforms during sleep.

Then the statistical properties of R-R interval are obtained for different sleep states and the variability of the interval for each state is measured using piecewise correlation dimension (PD2)[2] and approximate entropy.

II . METHOD

A. R peak detection algorithm

We used the modified nonlinear energy operator (MNEO)[1] as R peak detection algorithm. When operating on discrete time signals $x[n]$, discrete form nonlinear energy-tracking operator[3] ψ_c is defined as,

$$\psi_d[x[n]]=x^2[n]-x[n+1]x[n-1]. \qquad (1)$$

The above equation gives us a good approximation to express energy as a product of squared magnitude and squared frequency. To distinguish R wave from Q and S wave, MNEO is used. The MNEO is defined as follows:

$$MNEO=-x''[n]\,\psi_d[x[n]] \qquad (2)$$

where $x''[n]$ is the second derivative of $x[n]$.

B. Approximate entropy(ApEn)

Pincus proposed approximate entropy (ApEn)[5] as a mean to quantify complexitv of data sequences. Apen is defined as

$$ApEn(m,r,N) = \Phi^m(r) - \Phi^{m+1}(r) \qquad (3)$$

$$\Phi_m(r) = (N-m+1)^{-1} \sum_{i=1}^{N-m+1} \log C_i^m(r)$$

$$C_i^m(r) = \Pr\{ d[x(i), x(j)] \le r \mid i, m\}$$

where m is embedding dimension, x(i)=[u(i), u(i+1), ... ,u(i+m-1)], u(i)'s are data sequences, and d[] is operator to calculate distance between two vectors.

ApEn measures regularity of time series and is robust to noise-corrupted data as we have shown in [6].

C. Subjects

The R peak detection algorithm using MNEO is evaluated by applying to standard ECG waveforms such as the MIT-BIH database and applied to real ECG waveforms from nocturnal polysomnogram of patients with OSA syndrome. The patients' sleep state is evaluated to one of the states, WAKE, REM, and NREM (STAGE1, STAGE2, STAGE3, STAGE4) by an expert every 30 seconds.

III . RESULTS

For the purpose of evaluation of the proposed algorithm, it is applied to MIT-BIH arrhythmia database and its performance is evaluated by detection ratio and by false-negative ratio. And then the QRS complexes are detected from patients' nocturnal ECG waveforms. From the extracted QRS complexes the statistical characteristics of R-R interval are found for each sleep state.

A. Application to MIT-BIH database

MNEO is applied to ECG waveforms from MIT-BIH database the waveform.

The algorithm using MNEO produces 22 false-alarm(FA) beats (22/2572=0.0086) and 8 miss-detection(MD) beats (8/2572=0.0031) for a record 105 which contains more noisy blocks than others. It is comparable to Li's results that 15 FA beats and 13 MD beats have been produced[4]. Our alogrithm produces more FP beats but less FN beats. The algorithm is insensitive to the noise such as baseline drift and powerline interference.

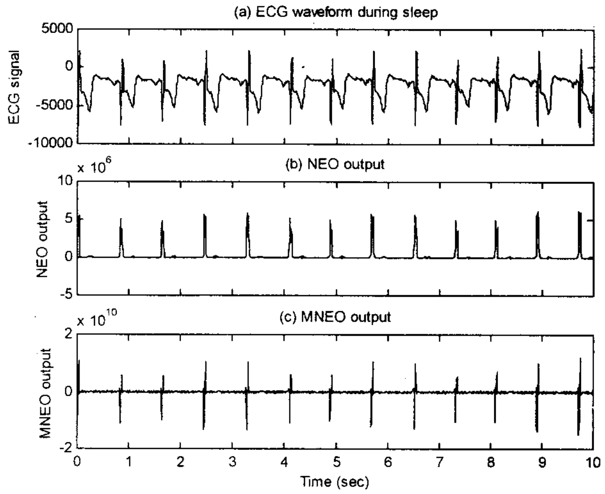

Fig.1. (a) ECG waveform during sleep, (b) NEO applied to waveform in (a), and (c) MNEO applied to waveform in (a).

B. Application to nocturnal sleep ECG waveforms

By applying the proposed algorithm to ECG waveforms of sleeping patients, some characteristics are obtained. Fig. 1 (c) shows that Q wave and R wave NEO has not distinguished are separated by MNEO.

C. *Analysis of the Heart-Rate variation during sleep*

Piecewise correlation dimension (PD2) estimates correlation dimension (D2) on nonstationary signals. But PD2 applied to sequences of R-R interval (Fig.2 (c)) shows that PD2 is inappropriate to extract explicit difference among sleep states.

When applying ApEn to sequences of R-R interval, we chose embedding dimension(m) to be 8. Fig.2 (d) shows that ApEn discerns between REM state and NREM states.

IV. DISCUSSIONS

In conclusion, it can be said that the complete detection of QRS complexes is difficult because of the variation in signal characteristics and the various noises. MNEO has performed well compared to the other methods in MIT-BIH database. Since the MNEO model has low computational complexity, it is applicable to real-time QRS complex detection processing.

Analysis of R-R interval in different sleep states gives physiological meanings. While the interval is somewhat periodic in NREM, the interval in REM varies irregularly.

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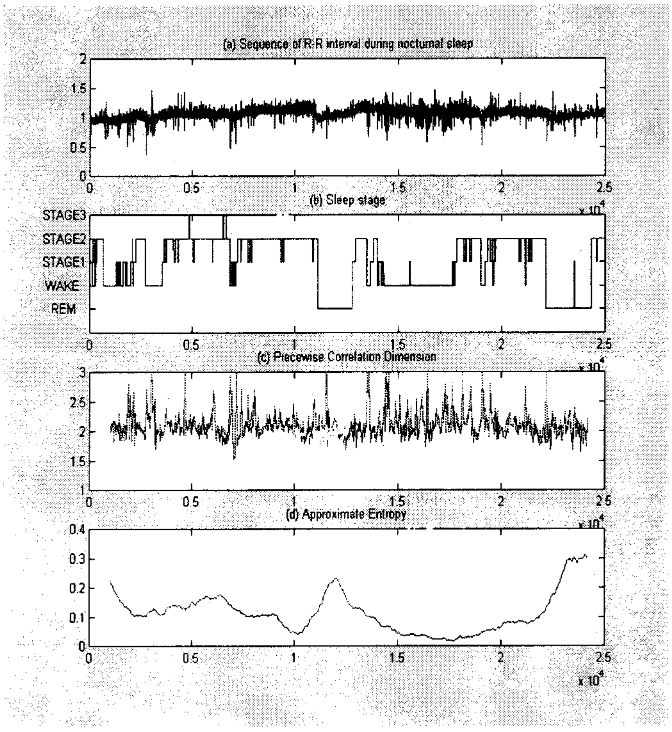

Fig.2. (a) Heart rate during nocturnal sleep, (b) Sleep state, (c) PD2 applied to waveform in (a), and (d) ApEn applied to waveform in (a).

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