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Multiscale permutation entropy analysis of electrocardiogram

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going with the changes of scale factor were discussed. Finally, we summarized the results of multiscale permutation entropy analysis of the three types of ECG and made relevant conclusions.

2. Multiscale permutation entropy

2.1. Permutation entropy

Permutation entropy is a simple and fast nonlinear method analyzing sequences' complexity. It can detect series' real-time dynamic characteristics, and has strong resistance to noise. Permutation entropy analysis includes four procedures, which are sequence reconstruction, sorting, probability and entropy calculation.

Assuming the time series $\mathrm{X}_L = \{x_1, x_2, ..., x_L\}$, sequence reconstruction is to convert X_L into multi-dimensional vector X_i. The conversion of the new vector is shown as equation 1:

$$\mathrm{X}_\mathrm{i} = \{x_i, x_{i+\tau}, ..., x_{i+(m-1)\tau}\} \tag{1}$$

m is embedding dimension, and τ is delay factor whose value is usually 1.

And then, each sequence in the reconstructed vector is rearranged in ascending order, which create a new vector composed by the position coordinates of the original elements in vector.

$$\pi_j = \{j_1, j_2, ..., j_m\} \tag{2}$$

Next, we need to count the type of the position orders and the number of their occurrences, and then calculate the probability of various permutations, calculate information entropy of all types' probability.

$$H_m = -\sum_{i=1}^{k} P_i \ln P_i \tag{3}$$

$$H = H_m / \ln(m!) \tag{4}$$

The normalized Permutation entropyis usually used in other studies. In this paper, H_m is applied rather the normalized form because H_m will has big contrast comparing to multiscale entropy.

2.2. Multiscale permutation entropy

Through coarse-grained process to the sequence, multiscale permutation entropy has optimization to original single-scale permutation entropy [10,11]. Coarse-grained process is to truncate the original sequence into several small sequences with same length.

$$y_j^s = \frac{1}{s} \sum_{i=(j-1)s+1}^{js} x_i \tag{5}$$

Equation 5 shows series' coarse-grained procedure, where s is scale factor. When the scale factor is 1, y_j^s is still the original signal, and sequence's complexity analysis is single-scale permutation entropy analysis. After coarse-grained processing, permutation entropy is applied to the new sequence.

2.3. Multiscale entropy

Traditional approaches may yield contradictory results in real-world datasets. Costa takes inherent multiple time scales into consideration, and makes contribution of sample entropy to propose a new entropy analysis algorithm, multiscale entropy. So multiscale entropy is a method to have coarse-grained process to time series, and