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Weighted permutation entropy based on different symbolic approaches for financial time series

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HIGHLIGHTS

- We introduce weighted permutation entropy and three different symbolic approaches.
- WPE based on symbolic approaches are applied to the US and Chinese stock markets.
- We reveal the influence of using different symbolic approaches on the WPE results.
- We make a comparison between the results of US and Chinese stock markets.

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ABSTRACT

In this paper, we introduce weighted permutation entropy (WPE) and three different symbolic approaches to investigate the complexities of stock time series containing amplitude-coded information and explore the influence of using different symbolic approaches on obtained WPE results. We employ WPE based on symbolic approaches to the US and Chinese stock markets and make a comparison between the results of US and Chinese stock markets. Three symbolic approaches are able to help the complexity containing in the stock time series by WPE method drop whatever the embedding dimension is. The similarity between these stock markets can be detected by the WPE based on Binary Δ-coding-method, while the difference between them can be revealed by the WPE based on σ-method, Max–min-method. The combinations of the symbolic approaches: σ-method and Max–min-method, and WPE method are capable of reflecting the multiscale structure of complexity by different time delay and analyze the differences between complexities of stock time series in more detail and more accurately. Furthermore, the correlations between stock markets in the same region and the similarities hidden in the S&P500 and DJI, ShangZheng and ShenCheng are uncovered by the comparison of the WPE based on Binary Δ-coding-method of six stock markets.

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1. Introduction

Recently different approaches have been introduced to rank stock markets in order to distinguish between emerging and developed economies [1–6]. It can be very helpful to analyze stock market data with the concept of entropy because of its ability on capturing the uncertainty and disorder of the time series without imposing any constraints on the theoretical probability distribution [7–11]. Permutation entropy (PE) is known as a complexity measure based on comparing neighboring values of each point and mapping them to ordinal patterns [12], while ordinal descriptors add immunity to large artifacts

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occurring with low frequencies, which makes it helpful. PE has been widely used in neural [13], electroencephalographic (EEG) [14–17], electrocardiographic (ECG) [18,19], and stock market time series [20] since it is applicable for different time series including regular, chaotic, noisy, or real-world time series. However, there is no information but the order structure when extracting the ordinal patterns for each time series, which is the main shortcoming in the PE. The reasons why the shortcoming make the analysis inconvenient can be listed as follows: first, the information containing in the amplitude in most time series may be lost due to extracting the ordinal structure simply; secondly, ordinal patterns where the amplitude differences between the time series points are greater than others should not contribute similarly to the final PE value; last, noise can lead to small fluctuations in the time series and affect the ordinal patterns, so these ordinal patterns should not be weighted equally toward the final value of PE. As a result, we apply the weighted permutation entropy (WPE), which alters the way PE handles the patterns extracted from a given signal by incorporating amplitude information, to counterweight these facts. WPE is capable of detecting abrupt changes in the signal and is effective on distinguishing the amplitude differences between the same ordinal patterns by assigning less complexity to segments that exhibit regularity or are subject to noise effects. WPE is superior when applying to signals containing amplitude-coded information because of its immunity to degradation by noise and (linear) distortion.

Meanwhile, we notice that different linear and nonlinear approaches have been used to characterize dynamical features. Diverse symbolic methods have been used for the physiological time series [21–27]. Inspired by these applications, we consider that dynamical aspects of time series derived from stock markets may be analyzed by means of symbolic approaches. In this paper, we desire to explore the WPE based on the different symbolic dynamics. Different approaches have been developed and applied to stock time series. One approach to symbolize the times series is based on the amount of deviation from the average closing price. Another approach spans the interval between the minimum and the maximum of the time series over a fixed amount of symbols [23]. This interval is divided into several equidistant steps. The third approach uses only two symbols and symbolizes the succession of acceleration and deceleration of the closing prices. Each approach to symbolize the stock time series retrieves specific information that cannot be gained with standard methods like e.g. spectral analysis. However, it is unclear if the approaches deliver different information when combining with the suggested WPE. In this study, the application of three different approaches of symbolizing the closing price series is performed before employing WPE.

The remainder of the paper is organized as follows. Section 2 briefly introduces the three different symbolic approaches and weighted permutation entropy. Section 3 describes the database used in this paper and obtained symbolic series. In Section 4, we present the empirical results obtained for US and Chinese market indices by WPE based on different symbolic approaches and make a comparison between the analyses of these two markets. Finally, we offer concluding remarks in Section 5.

2. Methodology

2.1. Weighted permutation entropy

Permutation entropy (PE) was introduced by Bandt and Pompe [12] as a complexity measure for nonlinear time series. PE characterize complexity by the ordinal pattern. It is known that PE neglects the amplitude differences between the same ordinal patterns and loses the information about the amplitude of the signal. Recently, WPE which extracted from a given signal by incorporating amplitude information is proposed [28]. Consider one time series $\{y_j\}_{j=1}^{M}$ and its time-delay embedding representation $Y_k^{m,\tau} = \{y_k, y_{k+\tau}, \dots, y_{k+(m-1)\tau}\}$ for $k = 1, 2, \dots, M-(m-1)\tau$, where m and τ denote the embedding dimension and time delay, respectively. WPE not only keeps the Shannon's entropy expression, but also extends the concepts of PE. To choose a weight value w_k is equivalent to select a specific feature from each vector $Y_k^{m,\tau}$. In this paper, we apply the variance of each neighbors vector $Y_k^{m,\tau}$ to compute the weights. Let $\bar{Y}_k^{m,\tau}$ denote the arithmetic mean of $Y_k^{m,\tau}$, or

$$Y_k^{m,\tau} = \frac{1}{m}\sum_{t=1}^{m} y_{k+(t-1)\tau}. \tag{1}$$

Hence, we can set each weight value as

$$w_k = \frac{1}{m}\sum_{t=1}^{m}[y_{k+(t-1)\tau} - Y_k^{m,\tau}]^2. \tag{2}$$

To compute WPE, each of the $T = M-(m-1)\tau$ subvectors is assigned a single motif out of $m!$ possible ones (representing all unique orderings of m different numbers). WPE is then defined as the Shannon entropy of the $m!$ distinct symbols $\{\pi_l^{m,\tau}\}_{l=1}^{m!}$, denoted as Π:

$$H_w(m,\tau) = -\sum_{l:\pi_l^{m,\tau}\in\Pi} p_w(\pi_l^{m,\tau}) \ln p_w(\pi_l^{m,\tau}) \tag{3}$$

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