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Procedia Computer Science 6 (2011) 52–56

Procedia
Computer Science

Complex Adaptive Systems, Volume 1
Cihan H. Dagli, Editor in Chief
Conference Organized by Missouri University of Science and Technology
2011 – Chicago, IL

Phase Synchronization Approach to Construction and Analysis of Stock Correlation Network

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Abstract

Stock correlation network, a subset of financial network, is built on the stock price correlation. It is used for observing, analyzing and predicting the stock market dynamics. Existing correlation methods include the minimum spanning tree (MST), planar maximally filtered graph (PMFG), and winner take all (WTA). The MST and PMFG methods lose information due to the connection criterion and thereby fail to include certain highly correlated stocks. The WTA method, when used for a non-linear system such as stock prices, fails to capture the dynamic behavior embedded in the time series of the stocks. In this paper we present a new method, which we call phase synchronization (PS) for constructing and analyzing the stock correlation network. The PS method captures the dynamic behavior of the time series of stocks and mitigates the information loss. To test the proposed PS method we use the weekly closing stock prices of the S&P index (439 stocks) from 2000-2009. The PS method provides valuable insights into the behavior of highly correlated stocks which can be useful for making trading decisions. The network exhibits a scale free degree distribution for both chaotic and non-chaotic periods.

Keywords: Stock Correlation Network; Phase Synchronization; Complex Network; Financial Network

1. Introduction

In the last decade, financial networks have attracted more attention from the research community. The stock correlation network is a subset of financial network which constructs a stock network based on correlation between stock entities (prices, trading volume and so on). The application of financial networks include examples such as

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doi:10.1016/j.procs.2011.08.012

company ownership based network, board of directors network that showed a power law distribution i.e., majority of companies were controlled by small number of people and small number of board members represented large number of companies respectively[1].

Several studies have proposed network based models for studying the stock correlation network [2][3][4][5]. Stock correlation network has been successful in predicting market movements. A study showed that the average distance between the stocks can be a significant indicator of market dynamics [6]. Andrew Lo and Khandaniy [7] analyzed the hedge funds based network (before the August 2007 stock market turbulence).

2. Existing methods for the construction of stock correlation network

The popular approach for constructing a stock correlation network involves the following steps:

1. The time series related to the stock is selected (e.g., daily prices, weekly prices, and trading volumes)
2. The cross correlation for each pair of stocks is computed and the cross correlation matrix [C_{ij}] is constructed.
3. Minimum spanning tree (MST) and planar maximally filtered graph (PMFG) method uses a metric distance d_{ij} [1] to establish links between the stocks. The d_{ij} metric is defined as

$$d_{ij} = \sqrt{2(1 - C_{ij})}$$

The MST and PMFG methods leads to loss of information, i.e., some high correlated nodes are discarded and low correlated nodes are retained because of the topological reduction criteria [8]. The WTA connection criterion overcomes the drawback of MST and PMFG [8]. In WTA method, the link between two stocks is established based on a threshold λ.

$$C_{ij} > \lambda$$

Tse, et.al [8] showed that for large values of threshold (e.g., 0.7, 0.8, or 0.9) the stock correlation networks exhibit a scale free behavior. For small values of threshold, the network tends to be fully connected and does not exhibit scale free distribution.

The cross correlation computation, when used for a non-linear system such as stock prices, fails to capture the dynamic behavior embedded in the time series. In this paper we present a new method, namely, phase synchronization (PS) method for constructing and analyzing the stock correlation network. We transform stock prices to a recurrence plot and then compute the cross correlation coefficient between two phase trajectories to quantify the phase synchronization. The cross correlation coefficient computed is then subjected to a cutoff threshold value (ε_{cutoff}) in order to establish links between pairs of stocks. The PS method captures the dynamic behavior of the time series and mitigates the information loss.

3. Phase Synchronization (PS) method

Two systems are phase synchronized when the difference of their respective phase is bounded. The approach to detect phase synchronization is based on the recurrence of the trajectories of nonlinear system in phase space. Recurrence plot was introduced to show a visual representation of recurrences in phase space [9]. The main step in the visualization is the calculation of the $N \times N$ matrix:

$$R_{i,j}(\varepsilon) = \theta\left(\varepsilon - \left\|\vec{x}_i - \vec{x}_j\right\|\right), \quad i,j = 1, \dots, N$$

where N is the number of measured points$\vec{x}$; ε is a threshold distance; θ is the Heaviside step function; and $\|.\|$ denotes a suitable norm in the phase space considered. $P(\tau)$ is the probability that the system returns to the ε; neighborhood of a former point x_i of the trajectory after τ time interval. One can detect and quantify the phase synchronization by comparing $P(\tau)$ for the both systems which is defined as follows: