LETTER

# Stock Index Trend Analysis Based on Signal Decomposition

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**SUMMARY** A new stock index trend analysis approach is proposed in this paper, which is based on a newly developed signal decomposition approach - adaptive Fourier decomposition (AFD). AFD can effectively extract the signal's primary trend, which specifically suits the Dow Theory based technique analysis. The proposed approach integrates two different kinds of forecasting approaches, including the Dow theory the RBF neural network. Effectiveness of the proposed approach is assessed through comparison with the direct RBF neural network approach. The result is proved to be promising.

***key words:*** *adaptive Fourier decomposition, the Dow theory, RBF neural network, stock index trend forecasting*

## 1. Introduction

A major challenge confronting speculators, investors, and businessmen is to accurately analyze and forecast the index trend of the stock market, which is a highly complex and non-linear dynamic system. There are many factors interacting in stock market, including political events, firms' policies, general economic conditions, interest and exchange rates, investors expectations and psychological factors, etc. Therefore, financial time series are among the 'noisiest' and most difficult signals to analyze [1].

There has been a lot of debate about the predictability of the stock price. One side thinks that the stock price changes are independent of the past and follow a random walk [2]. Any change in price represents the immediate reaction to an instantaneous news event or to new and unexpected changes in supply-demand figures. According to this "efficient market hypothesis", price changes are unpredictable, and forecasting in a financial market is a hopeless effort. Another side argues that the financial markets are somewhat predictable. The existence of so many price trends in financial markets and the un-discounted serial correlations among fundamental events and economic figures affecting the markets are two of many evidences against the unpredictable opinion [1]. Based on the views of the Nobel prize winner in 2013 [3], [4], index changes in a short period are unpredictable, however, the trend can be predicted over a substantial period of time. Our paper takes the latter view and tries to analyze the stock index trend for a long term.

The Dow Theory is the basis of many analysis techniques [5], [6]. Though it was founded over 100 years ago, it remains the most commonly used method by U.S. investors to predict the stock market price fluctuations. The basic premise of the Dow theory suggests that all information - past, current and even future - is discounted in the markets and reflected in the prices of stocks and indexes [7]. "All information" in the Dow theory includes every factor that could possibly impact the financial market, from the emotions of investors to inflation and interest-rate data, along with pending earnings announcements to be made by companies after the close. The only information excluded is that which is unknowable, such as a massive earthquake. But even the risks of such an event are priced into the market [7]. So the Dow theory is mainly focused on the prevailing trend in the market, which simplifies the investment decision to following the results of the analysis technique adopted.

Signal processing is a fundamental tool in many engineering and scientific analysis methods, including the financial data analysis. The purpose is to extract information from the original signal to reveal the underlying mechanism of various physical phenomena. The efficiency and quality of the signal processing depends strongly on the signal decomposition approach. The adaptive Fourier decomposition (AFD) is a newly developed signal decomposition approach with well proven mathematical foundations [8], [9]. It is an extension of the Fourier transform and has characteristics different from those of Fourier transform. AFD is especially good at extracting the trend of the non-stationary signal based on the desired accuracy of the approximation. So it is suitable to be used in long term trend extraction.

There have been some literatures using signal decomposition analysis approaches, such as wavelet analysis, for the stock movement forecasting [10], [11]. However, in general, signal decomposition based approach has not been well emphasized in this area. AFD based index trend analysis approach is proposed in this paper. The approach integrates two different kinds of forecasting approaches together. One is the AFD and the Dow theory combined technique analysis for the current market trend forecasting; the other is the AFD and the neural network combined index movement prediction for the near future.

This paper is organized as follows. The theory foundations, including the AFD algorithm, the Dow theory, and the

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radial basis function (RBF) neural network, are introduced in Sect. 2. The proposed approach is presented in Sect. 3. The experimental results are shown in Sect. 4. The conclusions are drawn in Sect. 5.

## 2. The Theory Foundation

### 2.1 The Brief Theory Foundation of AFD

AFD was motivated by the fact that Gabor's [12] method does not always produce analytic signals of non-negative instantaneous frequency (IF) [13]. To stick on the analytic signal idea, one has to accept that not all analytic signals have non-negative analytic phase derivative, or IF. This suggests seeking ways to approximate the given signal by appropriate basic signal with non-negative analytic IF, viz., monocomponents [13]. Progress has been made along this direction in which AFD is a core concept in the theory and practice. The brief explanation of AFD is provided below. The detailed theoretical foundation can be found in [8], [9].

AFD decomposes any given analytic signal of finite energy into a linear combination of a type of basic normal mono-component signals called modified Blaschke products. For a real-valued signal $f$ defined on the unit circle, AFD is to be applied to its Hardy space projection

$$f^+ = \frac{1}{2}(f + iHf) + \frac{c_0}{2}, \tag{1}$$

where $Hf$ is the circular Hilbert transform of $f$ with the formula

$$f^+(e^{it}) = \sum_{k=1}^{\infty} < f_k, e_{a_k} > B_k(e^{it}), \tag{2}$$

where

$$e_{a_k}(e^{it}) = \frac{\sqrt{1-|a_k|^2}}{1-\bar{a}_k e^{it}}, \tag{3}$$

$$a_k = \mathrm{a}rgmax\{\sqrt{1-|b|^2}|f_k(b)| : b \in \mathrm{t}he\ unit\ disc\}, \tag{4}$$

$$B_k(e^{it}) = e_{a_k}(e^{it}) \prod_{l=1}^{k-1} \frac{e^{it}-a_l}{1-\bar{a}_l e^{it}}, \tag{5}$$

$$f_k(e^{it}) = \frac{f_{k-1}(e^{it}) - < f_{k-1}, e_{a_{k-1}} > e_{a_{k-1}}(e^{it})}{\frac{e^{it}-a_{k-1}}{1-\bar{a}_{k-1}e^{it}}}, k = 1, 2, \cdots \tag{6}$$

$$f_0 = f^+. \tag{7}$$

The algorithm stops at the step $N$ such that

$$\|f^+\| - \sum_{k=1}^{N}(1-|a_k|^2)|f_k(a_k)|^2 < \varepsilon \tag{8}$$

for the first time. The approximation to the original real-valued function $f$ is

$$f = 2Re\{\sum_{k=1}^{N} < f_k, e_{a_k} > B_k\} - c_0$$

$$= \sum_{k=1}^{N} \rho_k(t)\cos\theta_k(t) - c_0, \tag{9}$$

where

$$\rho_k(t)e^{i\theta_k(t)} = 2 < f_k, e_{a_k} > B_k(e^{it}) \tag{10}$$

$$c_0 = \frac{1}{2\pi}\int_0^{2\pi} f(e^{it})dt. \tag{11}$$

Practically we take the initial value $a_1 = 0$.

This article makes use the open algorithm code in the homepage of Qian: http://www.fst.umac.mo/en/staff/fsttq.html. There are three AFD algorithms. The algorithm used in this paper is Cyclic AFD.

### 2.2 The Dow's Three Movements

The Dow theory is the oldest and most famous one of the technical analysis theories. The basic principle of the theory was founded by Charles Dow, and was supplemented and developed late by Nelson and Hamilton et al [5]. The Dow theory identifies three trends within the market: primary, secondary and minor [5], [6]. The first and most important one is the primary trend, which consists of the broad upward or downward movements known as bull or bear markets. It may last for more than a year. In general, Hamilton believes that the average length of the bull market is about 27 months, and the average length of the bear market is about 15 months. The second and most deceptive one is the secondary reaction, which is often associated with a movement against the primary trend. It is an important decline in a primary bull market or a rally in a primary bear market. These reactions usually last from three weeks to three months. The third and usually unimportant movement is the daily fluctuation. Stocks move up, down, and sideways every day and for the most part those moves are meaningless. In our proposed approach, the Dow theory is used for the primary trend analysis.

### 2.3 The RBF Neural Network

The RBF neural network is one of the most widely used training artificial neural networks. It derives from the theory of function approximation. The principle involves the supervised learning method so as to minimize the objective function. There are three layers contained in RBF: input layer, hidden layer, and output layer. Prediction on stock index by RBF neural network consists of two steps, one is training or fitting of neural network with the current data, the other is prediction for the future trend. In the training step, the weights from the input to hidden layer are determined. The second step simply fits a linear model with coefficients to the hidden layer's outputs with respect to some objective function. The input into an RBF neural network is nonlinear while the output is linear. Due to their nonlinear approximation properties, RBF neural networks are able to model complex mappings [14].

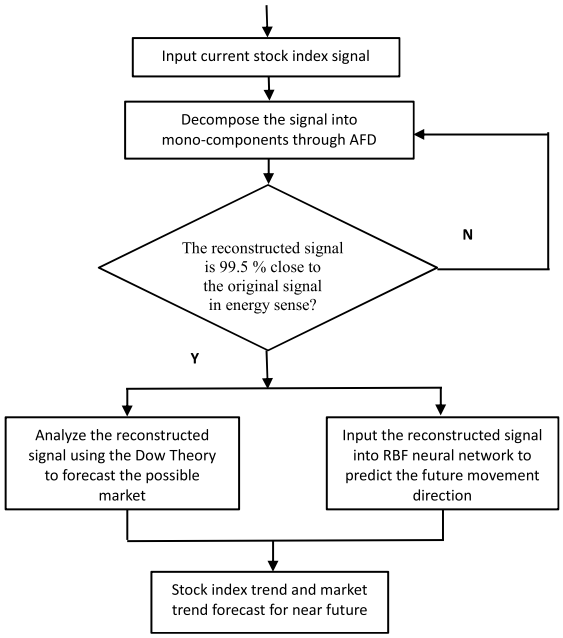


**Fig. 1** The flowchart of AFD based stock index movement forecasting model.

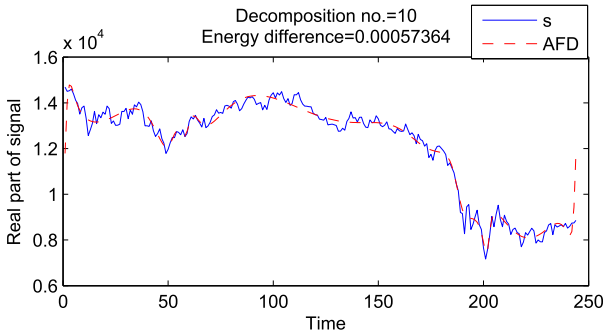


**Fig. 2** Original and AFD reconstructed signals of NIKKEI 225 in 2008.

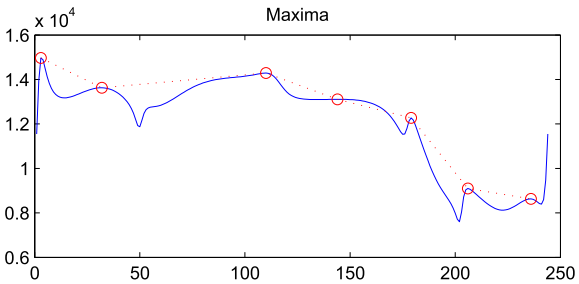


**Fig. 3** Maximum points in current primary trend.

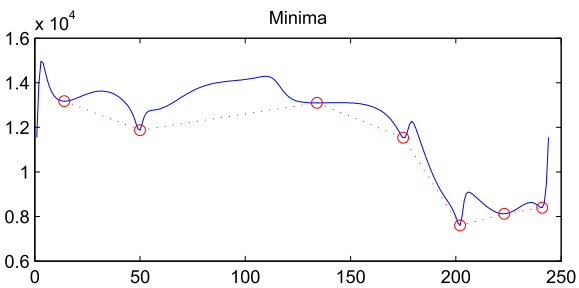


**Fig. 4** Minimum points in current primary trend.

## 3. The Principle of AFD Based Stock Index Analysis

The principles of the proposed AFD based stock index trend analysis approach include two steps. In step one, the current data of the stock index signal is first decomposed into mono-components by AFD algorithm. The mono-components are listed based on their frequencies, from lower frequencies to higher frequencies. The current primary index movement trend can be extracted by the partial sum of the first a few mono-components. Combining the current primary index movement trend with the Dow Theory, a bull market or a bear market can be summarized. In the second step, the extracted current primary index movement trend is combined with the RBF neural network to predict stock index movement trend for near future. At last, the forecasted result from the first step is combined with the prediction result from the second step to analyze possible market trend for the near future. The flowchart of the proposed approach is illustrated in Fig. 1.

## 4. Experiment Results

The data of the experiments are based on the real data in the stock market. They are the closing prices from Tokyo Stock Exchange NIKKEI 225. The data are selected for the period from the 1st January 2007 to the 30th June, 2013. The data were downloaded from the web site Yahoo! Finance [15]. Based on the Dow Theory, the primary trend may last for more than a year. So we take one year's data as the current data and next half year data as the future predicted data for analysis. There are five experiments that were conducted in this study. They correspond to use one year's current stock index data from year 2007 to 2012 to forecast the future half year trend, respectively.

Take an example of the NIKKEI 225 data in year 2008 as the current data. Original data and AFD reconstructed signal is shown in Fig. 2 The figure shows that AFD can extract very good trend of the signal. The energy difference between the original signal and the extracted trend is 0.00057 after 10 times decomposition. The Dow Theory is applied to analyze the trend market. As there are four consequent maximum points and three minimum points going down, the market is identified as bear market. The maximum points and minimum points in the past primary trend are shown in Fig. 3 and Fig. 4, respectively.

Take the primary trend in 2008 as the current data. They are inputted into the RBF neural network. The predicted result is compared with the real data in the early half year 2009. The root-mean-square error (RMSE) is 0.0075. The RBF result of AFD extracted primary trend is compared with the RBF result of the real data without applying the

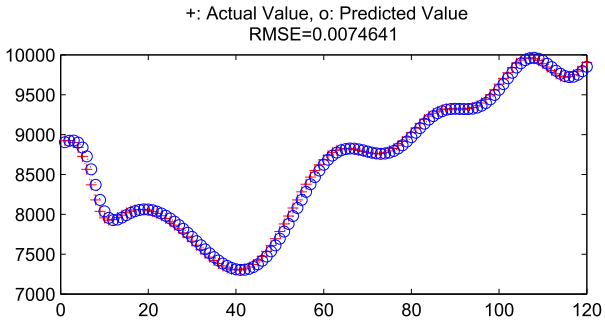


**Fig. 5** Primary trend forecast based on AFD and RBF.

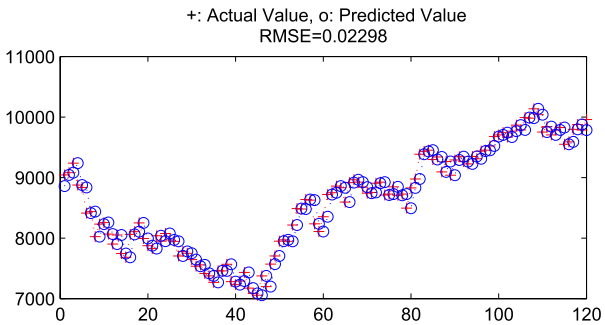


**Fig. 6** Primary trend forecast based on only RBF.

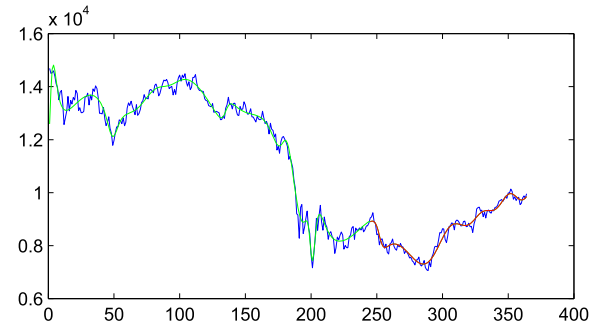


**Fig. 7** Original and trend signals.

AFD. Take the real data in 2008 as the current data. They are inputted into the RBF neural network. The predicted result is compared with the real data in the early half year of 2009. The root-mean-square error (RMSE) is 0.023. Both the results are illustrated in Fig. 5 and Fig. 6, respectively. Compare the results above, that AFD extracted primary trend can predict more accurate future trend. Combine both the forecasting results from The Dow Theory and RBF prediction, we can conclude that the primary bear market may change in the early half year of 2009 to bull market. The combined trend of both 2008 and the early half year of 2009 is illustrated in Fig. 7. The experiments are also conducted for year 2009-2012. The predicted market trend results are basically consistence with the real situations.

## 5. Conclusion

A signal decomposition based stock index trend analysis approach is proposed in this paper that can forecast near-term bull and bear markets. The basic principle of the system is the signal decomposition algorithm AFD. The specific characteristic of AFD is its powerful ability to extract the primary trend of the signal. It can also be extended to other directions of the financial data analysis area for the trend forecasting.

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