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High order fuzzy time series method based on pi-sigma neural network

Eren Bas [a,b,c,*], Crina Grosan [b,c], Erol Egrioglu [a], Ufuk Yolcu [d]

[a] Department of Statistics, Faculty of Arts and Science, Forecast Research Laboratory, Giresun University, Giresun 28200, Turkey
[b] Department of Computer Science, College of Engineering Design and Physical Sciences, Brunel University London, London UB83PH, United Kingdom
[c] Department of Computer Science, Babes-Bolyai University, Cluj-Napoca, Romania
[d] Department of Econometrics, Faculty Of Economic and Administrative Sciences, Forecast Research Laboratory, Giresun University, Giresun 28200, Turkey

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ABSTRACT

Fuzzy time series methods, which do not require the strict assumptions of classical time series methods, generally consist of three stages as fuzzification of crisp time series observations, determination of fuzzy relationships and defuzzification. All of these stages play a very important role on the forecasting performance of the model. An important stage of the fuzzy time series analysis is to determine the fuzzy relationships. Artificial neural networks seem to be very effective in determining fuzzy relationships that improve the accuracy of the forecasting performance. Several neuron models with different characteristics have been proposed so far. One of these models is Pi-Sigma neural network. An important advantage of Pi-Sigma neural network is that it requires fewer weights and nodes and has a lower number of computations when compared to multilayer perceptron. In this study, a new model for determining the fuzzy relationships for high order fuzzy time series forecasting which uses Pi-Sigma neural network is introduced. A modified particle swarm optimization model is used to train the Pi-Sigma network. We test the new model on two real datasets and we also perform a simulation study. The results are compared to the ones obtained by other techniques and show a better performance.

1. Introduction

Time series forecasting is an important problem in finance, energy, etc. The main purpose, in a time series forecasting problem, is to obtain forecasts as accurate as possible. For that purpose, many methods have been proposed. These methods can be discussed under three basic titles. The first of them is conventional time series methods based on probability theory such as autoregressive moving average (ARMA) models (Box and Jenkins, 1976), time series regression, vector autoregressive models. Although these classical methods have been commonly used to forecast various time series, they have some strict assumptions such as a large sample, linear model, stationary and normal distribution. Therefore they can fail to forecast complex real-world time series since they do not satisfied relevant strict assumptions. The second of them is computational methods based on artificial neural networks (ANNs). The other kind of time series methods is fuzzy methods based on fuzzy set theory. Fuzzy time series methods constitute the important part of the methods used in time series forecasting problems and based on fuzzy set theory. They also do not require the assumptions which are valid for classical time series methods. Recent studies concentrate more on fuzzy time series methods as they do not require strict assumptions and, generally, provide a remarkable forecasting performance.

The fuzzy set was firstly introduced by Zadeh (1965) and has been applied in many areas since then. Fuzzy time series, firstly introduced in the studies of Song and Chissom (1993a), can be identified as time series whose observations are fuzzy sets. Fuzzy time series analysis methods have a wide application area and generally consist of three stages: fuzzification, determination of fuzzy relations, and defuzzification. Since all these stages play an important role on the forecasting performance of the model, forward a great number of studies that focus on these stages have been proposed by various researchers. Especially, in the determination of fuzzy relations, forecasting accuracy have been tried to improve in many studies via several methods having different viewpoints. In these studies, to determine the fuzzy relations, fuzzy relation operations by using fuzzy logic relation matrix and group relations tables, different kinds of ANN have been used.

When the matrix operations, fuzzy logic relations and group relations tables are used in the determination of fuzzy relations, it is came up against that complex and difficult operations, especially when the numbers of clusters is large. We can mention different kinds of ANN with different neuron models utilized in this stage of fuzzy time series analysis process such as multi-layer perceptron (MLP) with additive structure neuron model, multiplicative neuron model neural network (MNM-ANN) with multiplicative structure neuron model. Especially, MLP has

* Corresponding author at: Department of Statistics, Faculty of Arts and Science, Forecast Research Laboratory, Giresun University, Giresun 28200, Turkey.
E-mail address: eren.bas@giresun.edu.tr (E. Bas).

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been widely used to determine the fuzzy relations. But, MLP needs the complex architecture structure with the multi-layer i.e. a large number of weights and biases to get a well-trained network. Moreover, these networks converge very slowly in typical situations dealing with complex and non-linear problems (Shin and Gosh, 1991). This circumstance causes complexity in computation and time consuming, especially when the number of clusters or the inputs is large. A high-order network called by Shin and Gosh (1991) as pi-sigma neural network (PSNN) which uses multiplicative and additive neuron models in the network architecture can be used in the determination of fuzzy relation to avoid complexity in computation and exponential increase in the number of weights and biases and also computation time. The authors argued that PSNN requires less memory (weights and nodes), and at least two orders of magnitude fewer computations for similar performance level compared to multilayer perceptron, on a broad class of problems. PSNN has been used for time series forecasting problems in recent years. Tawfik and Liatsis (1997) and Ghazali et al. (2006, 2008) used PSNN for time series forecasting problems.

In this study, we propose a new methodology which uses PSNN to define fuzzy relationships in high order fuzzy time series and a modified PSO algorithm to train the weights of the network. We apply it to two well-known real world time series data. Besides, a simulation study is performed and the importance of the proposed method is emphasized. The results are compared to other existing methods and show that the proposed approach has better forecasting accuracy.

The structure of the paper is as follows: Section 2 includes a detailed literature review. The definitions of first and high order time series are defined in Section 3. The brief information for PSNN is given in Section 4. PSO is briefly summarized in Section 5. The new proposed method is introduced in Section 6 and the experimental results are analyzed in Section 7 and compared with some other existing techniques. The final section summarizes the conclusions and discussions of this study.

2. Literature review

Fuzzy time series were firstly introduced in the studies of Song and Chissom (1993a), where two types of fuzzy time series methods are mentioned: time variant methods and time invariant methods. A large variety of each of these methods exists in the literature as mentioned by Song and Chissom (1993b, 1994). The decomposition of universe of discourse is mostly used in the fuzzification stage and the intervals are determined arbitrarily in the studies of Song and Chissom (1993a, b, 1994), Chen (1996, 2002). Huarng (2001a, b) emphasizes the importance of the interval length in the forecasting performance and proposed two new techniques based on mean and distribution in order to find intervals. Besides these studies, computational intelligence algorithms have been frequently used in the fuzzification stage. Genetic algorithms are used to find the interval lengths in the studies of Chen (2002) and Chen and Chung (2006), and particle swarm optimization (PSO) is used in the studies of Davari et al. (2009), Fu et al. (2010), Hsu et al. (2010), Huang et al. (2011), Kuo et al. (2009, 2010) and Park et al. (2010). Uslu et al. (2013a) uses differential evolution algorithm, Yolcu et al. (2014) utilizes artificial bee colony, and Bas et al. (2014) uses modified genetic algorithm in the fuzzification stage.

In the determination of fuzzy relations, although fuzzy group relation tables are frequently used, artificial neural networks are one important alternative. Fuzzy relations are determined with fuzzy relation operations in the studies of Song and Chissom (1993b, 1994). These operations can be complex and time consuming, especially when the numbers of clusters is large. There are various methodologies adopted for finding fuzzy relations: the work of Song and Chissom (1993a, b, 1994) uses matrix operations, Chen (1996) uses fuzzy logic relations group tables, Cagcag Yolcu et al. (2016) proposes an approach based on operation of intersection, Aladag et al. (2010), Egrioglu et al. (2009a, b, c), Huarng and Yu (2006a, b), Sullivan and Woodall (1994), Aladag (2013) and Yolcu et al. (2013) use ANN.

The study of Egrioglu et al. (2009b) concentrates on bivariate high order fuzzy time series forecasting. Egrioglu et al. (2009a, b), Aladag et al. (2009, 2010), Egrioglu et al. (2009c), Aladag et al. (2012a, b), Egrioglu et al. (2009a), Yu and Huarng (2010), Yolcu et al. (2013), Egrioglu et al. (2009a, c, 2013), and Aladag (2013) use index number of fuzzy sets for ANN training. In these studies, the membership values of fuzzy sets are not taken into consideration. Yu and Huarng (2010) and Yolcu et al. (2013) use membership values of fuzzy sets for training of ANN. Aladag (2013) and Cagcag Yolcu (2013) use multiplicative neuron model neural network (MNM-ANN) instead of feed forward artificial neural network (FF-ANN). MNM-ANN is used to determine fuzzy relations of seasonal fuzzy time series in Aladag et al. (2012a, b). Egrioglu et al. (2015) use both MNM-ANN and membership values to determine fuzzy relations.

In the defuzzification stage, most of the existing work uses the centroid method. Chen (1996), Huarng (2001a), Huarng and Yu (2006a, b) use this method in their studies. Aladag et al. (2010) and Cheng et al. (2008a, b) employ adaptive expectation method instead.

For some studies in the literature establish Table 1 which includes summary info of them.

The methods proposed in the literature to determine fuzzy relations use first-order ANN models such as MLP and SMNM-ANN. However, the use of high-order ANN models such as PSNN to determine fuzzy relations would be useful in explaining more complex relations. In this paper, this gap in the literature was tried to be filled.

It is well known that the way in which the fuzzy relations are determined plays an important role on the forecasting performance. The matrix operations and the fuzzy group relation tables become complicated in high order models. To eliminate this complexity, FF-ANN is preferred as an alternative to fuzzy group relation tables. The work of Aladag (2013) employs MNM-ANN instead of FF-ANN. Although FF-ANN has superior adaptability to the data, it needs a multi-layer and complex architecture structure to do this. It means that it needs a large number of weights and biases to get a well-trained network. This circumstance leads to slowly convergence to optimal solution. When MNM-ANN uses to determine the fuzzy relations, we have to face the problem of model-based structure of MNM-ANN because of its' feature of having just one neuron. From this point of view, in the fuzzy time series literature we prefer to use PSNN which does not consist both of these problems in the determination of fuzzy relations.

3. Fuzzy time series

The definition of fuzzy time series was firstly introduced by Song and Chissom (1993a, b, 1994). The basic preliminaries for fuzzy time series are given in what follows: Let U be the universe of discourse, where $U = \{u_1, u_2 \cdots, u_b\}$. A fuzzy set A_i of U is defined as $A_i = f_{A_i}(u_1)/u_1 + f_{A_i}(u_2)/u_2 + \cdots + f_{A_i}(u_b)/u_b$, where f_{A_i} is the membership function of the fuzzy set A_i; $f_{A_i} : U \rightarrow [0,1]$. u_a is a generic element of fuzzy set A_i; $f_{A_i}(u_a)$ is the degree of belongingness of u_a to A_i; $f_{A_i}(u_a) \in [0,1]$ and $1 \leq a \leq b$.

Definition 1. Let $Y(t)(t = \cdots, 0, 1, 2, \ldots)$, a subset of real numbers, be the universe of discourse on which fuzzy sets $f_j(t)$ are defined. If $F(t)$ is a collection of $f_1(t), f_2(t), \ldots$ then $F(t)$ is called a fuzzy time series defined on $Y(t)$.

Definition 2. Fuzzy time series relationships assume that $F(t)$ is caused only by $F(t-1)$, then the relationship can be expressed as: $F(t-1) \rightarrow F(t)$. This model is called as first order fuzzy time series forecasting model.

Definition 3. If $F(t)$ is caused by $F(t-1), F(t-2), \ldots, F(t-m)$, then this fuzzy logical relationship is represented by $F(t-m), \ldots, F(t-2), F(t-1) \rightarrow F(t)$ and it is called m order fuzzy time series forecasting model.