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Ahmed Tealab
Computer Science Department, Institute of Statistical Studies and Research, Cairo University,
a.tech.gouda@gmail.com

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Time series forecasting using artificial neural networks methodologies: A systematic review

Ahmed Tealab

Computer Science Department, Institute of Statistical Studies and Research, Cairo University, Giza, Egypt

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Abstract

This paper studies the advances in time series forecasting models using artificial neural network methodologies in a systematic literature review. The systematic review has been done using a manual search of the published papers in the last 11 years (2006–2016) for the time series forecasting using new neural network models and the used methods are displayed. In the covered period in the study, the results obtained found 17 studies that meet all the requirements of the search criteria. Only three of the obtained proposals considered a process different to the autoregressive of a neural networks model. These results conclude that, although there are many studies that presented the application of neural network models, but few of them proposed new neural networks models for forecasting that considered theoretical support and a systematic procedure in the construction of model. This leads to the importance of formulating new models of neural networks.

Keywords: Forecasting; Nonlinear time series; Neural networks; Moving averages

1. Introduction

Time series is a general problem of great practical interest in many disciplines. Because it allows you to discover, with some margin of error, the future values of a series from its past values. In the relevant literature there have been numerous successful applications in different fields, such as the economy, finance and hydrology.

Box and Jenkins [20], in the late 70s, made an important work in studying applications composed of mathematical linear models. These models represent Autoregressive (AR) and Moving Averages (MA) processes. While in the AR processes it is assumed that the current value of the time series is a linear combination of its past values. Processes in the MA are supposed that the current value is a function of random interference passes or perturbations that have affected the series. Many practical experiments have demonstrated that this approach makes it possible to represent the dynamics of many real time series. That class models is popularized in both the academic and professional fields.

However, it has also been found that many real time series seem to follow non-linear behavior and the approach of Box and Jenkins is insufficient to represent their dynamics [1,4]. Thus in the most relevant literature have been presented a wide range of models that suggest different mathematical representations of the non-linearity present in the data [4,5], such as the models based on schemes [4] and different types of Artificial Neural Networks (ANN) [6–8]. Some other literature reviews focused on one type of forecasting, one-step or multi-step ahead forecasting, and comparing the proposed strategies in theoretical and practical terms [33].

Particularly, the ANN has received considerable attention by the scientific community, which has been translated into a major investigative effort. The evidenced of that is the large number of publications on this topic; it is as well, as a simple search in SCOPUS chains with “neural networks”

E-mail address: a.tech.gouda@gmail.com.
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and "time series" found more than 4000 reported documents; many of them might be irrelevant to the needs of the researcher.

Certainly a significant number of ANN architectures have been proposed in the literature. The most proposed models are based on adding a non-linear function to AR model, as in the case of the artificial neural network with dynamic architecture (DAN2) [9] or the autoregressive neural networks as [2,10,21]; applying a nonlinear function to the AR model, as in the case of multilayer perceptron [3]; or hybridize with other models that capture the linear component [21].

Despite the success of the ANN, and its true persist since the 90s; it is also apparently several problems related to the model proper specification [8]. This is evidenced by the fact that most of the decisions in the process specifications are subjective and are based on the experience of the modeler. Thus, seemingly, has not been fully reached systematic procedure for formal specification of ANN models [10].

Another persistent problem is that there is a noticeable absence of developments in the extension of the MA model using ANN in comparison with the extensions of the AR model. In this way, it can be considered that a large part of ANN proposals in the literature are based on a non-linear autoregressive structure, as already indicated. This restriction does not allow you to properly model time series that contain an inherent of MA component [11]. The dynamic behavior of most of the time series in our real life, with its autoregressive and inherited moving average terms, pose the challenge to forecast nonlinear times series that contain inherited moving average terms using computational intelligence methodologies such as neural networks [32].

Rationing raised here is why the research questions formulated below: RQ1: What are the new models based on artificial neural networks that have been proposed since 2006 until the year 2015? RQ2: Which of the proposed models considered a different structure to the autoregressive? RQ3: Published studies present a systematic approach, step by step, for the construction of the model? RQ4: What are the remaining problems to be solved in new proposed approaches? Thus, the aim of this work is to answer the previous research questions on the basis of analysis of the more relevant documentary evidence presented in the literature using the methodology of systematic literature review (SLR).

The importance of this work is based on two aspects: first, literature reviews conducted till now have not analyzed the advances with a systematic approach to a specific strategy; for example, that not analyzed whether the selected items that develop such aspects as selection of architecture, selection of input variables, estimate parameters or evaluation model. Such reviews don't analyze whether proposals are developed based on different components to the autoregressive or not. Second, in this paper, we discuss some outstanding problems and that may be the starting point for future research.

The remainder of this paper is organized as follows. In Section 2, the research methodology is presented. In Section 3 describes the obtained results; then, in Sections 4 and 5 present the discussion and conclusions respectively.

2. Methodology

In this study the research methodology applied SLR developed by Kitchenham [12] in the context of software engineering. This methodology promotes the use of a systematic strategy for defining the research questions, declaring the search strategy, identifying primary studies, data synthesizing and data analysis the documentary evidence to answer a particular research question. The SLR can overcome their own shortcomings in informal or narrative reviews, which are among: the absence or poor formulation of research questions or the lack of an explicit description of how it was selected the documentary evidence.

The objective of this SLR is to identify the most important theoretical contributions in the development of artificial neural network models for the forecasting of non-linear time series, which were performed in the period between 2006 and 2016. Similarly, also seeks to identify new research problems originated from the published proposals.

2.1. Search process

The search process consisted of a manual search of articles published in journals serials for the period between 2006 and 2016. The search was carried out using the bibliographic system SCOPUS, which includes one of the largest collections of abstracts, bibliographical references and indexes on the planet. Two criteria were used. The first criterion chain was used: TITLE-ABS-KEY (nonlinear neural model for forecasting) AND DOCTYPE (ar or rev) AND PUBYEAR AFT 2005. The second approach uses the search string: TITLE-ABS-KEY (neural networks AND nonlinear time series modeling) AND DOCTYPE (ar) AND PUBYEAR AFT 2005.

2.2. Inclusion and exclusion criteria

In this research, a single inclusion criterion was defined: Article proposes a new type of neural network to predicting time series. Additionally, the articles that met with some of the following were excluded:

1) An application of ANN is presented without any formal theoretical development or the analyzed job does not define a research question.
2) It is replicated a study or methodology without any conceptual development or practical novel.

2.3. Quality assessment

To assess the quality of the finally selected articles, the following questions were used: QA1 Is it explicit mathematical formulation of the model? QA2 Is it defined the process of estimating parameters for the new model? QA3 Does the study specify criteria for selecting the relevant variables? QA4 Does the study present a method for determining the appropriate complexity (number of layers or neurons) model? QA5 Is there an

evaluation or diagnosis for the model? QA6 Does it examine the feasibility of the proposed methodology by means of an application to a real case? QA7 Does it specify the procedure for training the model (data transformation, initial values of the parameters, stop criterion, etc.)? Scores to questions were given as follows: QA1 Y (yes), the mathematical formulation of the new model is presented explicitly in the article; P (partially), the mathematical formulation is implied; N (no) is not defined explicitly mathematical formulation and can easily be inferred from reading the article. QA2 Y (yes), describes in detail a procedure for estimating the parameters of the model; P (partially), points to a procedure or suggests the reading of other studies; N (no) does not address the issue of parameter estimation. QA3 Y (yes), Article explicitly states criteria for the selection of relevant variables; P (partially) procedures are indicated or suggested reading other studies; N (no), the problem is not addressed selection of relevant variables. QA4 Y (yes), there is a method or explicit criterion for determining the complexity of the model (layers or nodes); P (partially), do not explicitly specify how to define the complexity of the model or appropriate references to other articles; N (no), it does not address the problem of determination of the complexity of the model. QA5 Y (yes), is shown explicitly a procedure to diagnose the model; P (partially), the diagnosis of the model is done implicitly or refers to a method proposed in another article; N (no), is not defined and it is recommended that a diagnostic method for the proposed model. QA6 Y (yes), the authors apply the model to predict a series of real-time; P (partially), the developed model is used to predict a series of simulated time; N (no), is not performed by an application of the proposed model. QA7 Y (yes), the formulation of the training algorithm is explicit in the article; P (partially), the training algorithm is implicit or reference is made to another study; N (no), is not defined and it is recommended that a training algorithm. For questions QA1 to QA7 assigned the following Scores: $Y = 1, P = 0.5$ and $N = 0$. As a complement to the analysis of the selected models were additionally considered the following criteria: QA8 Relationship between the number of citations received by the article and time published (i.e. the difference between 2010 and the year of publication of the study). QA9 Value of the prompt Scimago Journal rank, which reflects the prestige of the source, that is, the value of the citations weighted by document in accordance with the year of publication of the article. QA10 Source Normalized Impact per Paper (SNIP) that defines the ration for the count of citations of the magazine article and the potential of citations in the field of interest. In addition, also was identified if the proposed models considered a different structure to the autoregressive.

2.4. Data collection

The data extracted from each study were: name of the journal where the article was published with full references, the topic of research and summary of the study, the objective or research question, the quality of the research, the results obtained with respect to the topic under consideration, the future research proposals by the study, the number of citations received, the indicators "Source-Normalized Impact per Paper" (SNIP) and "SCImago Journal Rank " (SJR) in the year of publication of the article. The SJR indicator corresponds to the number of citations received by the article for a period of three years, which are weighted according to the prestige and the thematic area of the journal in which the article analysis was published. The SNIP indicator is calculated taking into account the number of citations received by the article, the number of published articles and quotes of the potential area.

3. Obtained results

3.1. Search results

When using the search strings in the SCOPUS system automatically recovered a total of 4021 publications. Then, manually applied the criteria of inclusion and exclusion, which led to the selection finally, a total of 17 articles, whose references are listed in Table 1. In this process, it is worth noting that although there are a very high number of publications on ANN, there are really very few studies that propose new models with an appropriate theoretical support. Also, it was found that there is not a stable number of publications per year in which there are new theoretical advances; the maximum number of publications occurred in the year 2005.

3.2. Quality assessment

For the 16 studies were finally selected with the quality criteria defined in Section 2, the results obtained are presented in Table 2, in which each row represents one of the selected studies. In Table 2, columns 3 to 9 show the degree of compliance with the criteria of quality questions defined by the QA1 QA7; the column 10 collects the total score obtained in relation to the questions to QA1 QA7; the columns 11 to 13 show the results obtained by applying the supplementary criteria QA8 to QA10. Finally, the 15th column gives information on the methodology proposed in each study (hybrid, or different combination of the above); an asterisk (*) in this column indicates that it proposes a different schema to the regressive. The results of the analysis of quality show that the average score is 4.35 ± 1.302, which means that the average quality of the selected studies varies between 3.0 and 5.6. Note that this range of values differs significantly from the ideal score of 7, which represents an article that meets all the requirements necessary to have an appropriate strategy for the selection of the final model. This indicates that, in general, the models developed between 2006 and 2016 do not completely satisfy all the requirements to develop a new model based on neural networks.

Finally, it should be noted that the only studies S1 and S6 are fully compliant with the seven criteria for the specification of the model.

4. Quality factors

When we analyzed the selected articles, it was found that only three proposals consider a different process to the autoregressive: Khashei and Bakhari [21], Zhang [14], Wang et al. [27] and Chieh-C Young, Wen-C Liu, and Wan-Lin Hsieh [30].

Table 1
Description of selected studies.

ID	Authors	Year	Proposed model	Conclusion
S1	Medeiros, Teräsvirta and Rech [15]	2006	AR-NN	It is proposed a hybrid model between an autoregressive model and an ANN model with a single hidden layer. The proposed method of model allows you to specify parsimoniously models at a low computational cost.
S2	Pang et al. [16]	2007	NLPMANN	It presents and test a non-linear disturbance model based on neural networks. This is successfully applied to the simulation of rainfall in a watershed.
S3	Hassan, Nath and Kirley [17]	2007	–	It proposed a hybrid model based on the hidden Markov model (HMM), ANN and Genetic Algorithms (GA), to predict the behavior of the financial market.
S4	Li et al. [18]	2008	AR*-GRNN	It considered a combined model, consisting of an AR* model and a generalized regression neural networks model (GRNN, by its initials). The results indicate that the method is effective to combine the time-series models with models of neural networks, taking the advantages of decade model.
S5	Khashei, Reza Hejazi and Bijari [19]	2008	–	It proposes a new hybrid method based on the basic concepts of ANN and the fuzzy regression models, which produces more precise results for incomplete data sets.
S6	Chen and Chang [20]	2009	–	It is considered an Evolutionary Artificial Neural Network model (EANN) to automatically construct the architecture and the connections of the weights of the neural network.
S7	Khashei and Bijari [21]	2010	–	It presents a new hybrid ANN model, u sing an ARIMA model to obtain forecasts more accurate than the model of neural networks. In the first stage of the hybrid methodology, fits an ARIMA model and, in the second, is taken as network inputs the residuals of the ARIMA model and the original data.
S8	Wong, Xia and Chu [22]	2010	ADNN	It is considered a new ANN model with adaptation metrics for the entries, and with a mixing mechanism for the outputs of the network.
S9	Wu and Shahidehpour [23]	2010	AWNN Time series	Propose a hybrid model based on an adaptive Wavelet Neural Network (AWNN) and time series models, such as the ARMAX and GARCH, to predict the daily value of electricity in the market. They show better results in the forecasts than those reported in the literature.
S10	Gheyas and Smith [24]	2011	GEFTS-GRNN	It features and ensembles a regression neural network model to predict widespread time series, which is a hybrid of different algorithms for machine learning. With this model combines the advantages joint that represent the algorithms, but has a high computational cost.
S11	Alavi and Gandomi [25]	2011	ANN-SA	It is considered an ANN model whose training is done by means of the simulated annealing algorithm (SA). This model is proposed to study some characteristics related to seismic events, using experimental data.
S12	Cui, Liu and Li [26]	2012	NWESN, BAESN, MESN	It Proposes three new neural network models based on Echo State Network (ESN) and with theory of complex networks. Although these models have a structure more complex than the original model ESN. They show that they yield more accurate forecasts.
S13	Yolcu, Egrioglu and Aladag [27]	2013	L&NL-ANN	It presents a new model that considers at the same time the ANN of linear and nonlinear time series structures. The network is trained using the Particles Swarm Optimization algorithm (PSO). The authors show that the proposed model allows you to obtain better results compared to some traditional models.
S14	Wang et al. [28]	2013	ARIMA-ANN	It is considered a hybrid model between ANN and the ARIMA model, in order to integrate the advantages of both models. The new model was tested in three databases, yielding good results.
S15	Xuejun Chen et al. [29]	2014	SVR-NN - GA	Proposes a hybrid approach wavelet denoising (WD) techniques, in conjunction with artificial intelligence optimization based SVR and NN model. The computational results reveal that cuckoo search (CS) outperforms both PSO and GA with respect to convergence and global searching capacity, and the proposed CS-based hybrid model is effective and feasible in generating more reliable and skillful forecasts.
S16	Chieh Young et al. [30]	2015	3D hydrodynamic, (ANN), ARMAX), hydrodynamic and ANN	A 3D hydrodynamic model, ANN model (BPNN), AR with exogenous inputs, ARMAX) model, and a combined hydrodynamic and ANN model integrated to more accurately predict water level fluctuation. The proposed concept of combining three-dimensional hydrodynamic model used in conjunction with an ANN is a novel one model which has shown improved prediction accuracy for the water level fluctuation.

(*continued on next page*)

Table 1 (*continued*)

ID	Authors	Year	Proposed model	Conclusion
S17	Jie Wang et al. [31]	2016	ERNN-STNN	Propose a hybrid model based on Elman recurrent neural networks (ERNN) with stochastic time effective function (STNN), the empirical results show that the proposed neural network displays the best performance between linear regression, complexity invariant distance (CID), and multi-scale CID (MCID) analysis methods and compared with different models such as the back-propagation neural network (BPNN), in financial time series forecasting.

On the other hand, we analyzed the correlation between the score obtained and the date of publication of the article which shows that the studies published in 2006, 2007 and 2009 are characterized by similar values and high scores, unlike the publications from the years 2008 and 2013 that have heterogeneous values.

Note that the published studies in the final periods are characterized by low scores, that is, they fail to meet a large part of the criteria necessary for an appropriate formulation of a forecasting model based on artificial neural networks.

In addition, it was found that the correlation coefficient between the score obtained and the reason of citations per year of the studies is −0, 1505 (p-value = 0.5120), indicating that the quality of the specification of the model has no influence on the number of citations received by year.

In addition to analyze the indicators SJR and SNIP (columns 12 and 13 of Table 2), it was found that there is not a significant relationship between them and the total obtained score. The Spearman correlation coefficient between JRS and the score was 0.2462 (p-value = 0.2821) and between the SNIP and the score was 0.2690 (p-value = 0.2384).

5. Discussion

In this section we answer the research questions raised. RQ1. What are the new models based on artificial neural networks that have been proposed since 2006 until the year 2016?

Between the years 2006–2016 have been developed 17 new models that meet all the inclusion and exclusion criteria defined in this research, which are listed in Table 1.

RQ2. Which of the proposed models considered a different structure to the autoregressive?

It was found that only 17% of the reviewed models in this study considered a different process to the Autoregressive. In the models proposed by Khashei and Bakhari [21], Zhang [14], Wang et al. [28] and Chieh-C Young, Wen-C Liu, and Wan-Lin Hsieh [30] used a similar hybrid methodology: initially adjusts a linear time series model, and are subsequently used the residuals of this model as the input variables of an ANN model.

In addition, the authors present evidence that the predictions obtained with hybrid models are more accurate than those obtained by traditional models of artificial neural networks, such as the back propagation with a single hidden layer.

However, the four models found in this study have a low score, which indicates that they do not fully comply with the specification of a systematic process for the construction of the model. On the other hand, while the theory indicates that an AR model of a sufficiently high order can be approximated with sufficient MA precision process of a low order; in the case of non-linear this is not true. Burgess and Refenes [11] demonstrate empirically that a non-linear autoregressive model (NAR) of a high order is not capable of represent a process of non-linear moving averages (NLMA) of low-order.

Table 2
Quality assessment.

ID	QA 1	QA 2	QA 3	QA 4	QA 5	QA 6	QA 7	Score	QA 8	QA 9	QA 10	Methodology
S1	Y	Y	Y	Y	Y	Y	Y	7.0	5.7	0.392	0.908	HYBRID
S2	P	Y	N	Y	N	Y	P	4.0	0.8	1.555	1.943	HYBRID
S3	Y	N	N	N	Y	Y	Y	5.0	13.8	1.094	1.675	HYBRID
S4	Y	N	N	N	Y	P	P	3.0	1.2	0.390	1.068	COMBINATION
S5	Y	Y	P	N	Y	Y	P	5.0	11.0	2.064	1.985	HYBRID
S6	Y	Y	Y	Y	Y	Y	Y	7.0	10.5	1.678	1.836	OTHER
S7	Y	P	N	N	P	Y	N	3.0	14.0	1.173	1.766	HYBRID
S8	Y	P	N	N	P	P	P	3.0	7.3	2.606	2.350	OTHER
S9	Y	P	Y	N	Y	Y	Y	4.5	7.0	2.420	2.989	HYBRID
S10	P	N	P	N	Y	Y	P	3.5	3.0	1.206	1.910	HYBRID
S11	Y	Y	P	N	Y	Y	Y	4.5	15.5	1.301	2.619	OTHER
S12	P	P	N	N	Y	P	P	3.0	–	0.876	1.102	OTHER
S13	Y	Y	N	N	Y	Y	Y	5.0	–	–	–	HYBRID
S14	N	N	N	N	Y	Y	P	2.5	–	–	–	HYBRID
S15	P	N	P	N	Y	Y	P	3.5	–	–	–	HYBRID
S16	Y	Y	P	N	Y	Y	P	5.0	–	–	–	COMBINATION
S17	Y	P	P	Y	Y	Y	P	5.5	–	0.232	0.570	COMBINATION

In this case, there is a decrease in the content of information captured by the model NAR, possibly explained by the increase in the variance due to the high number of required parameters. This causes the degradation of the generalization ability of the model.

As well, of the research question RQ2 emerges the thematic future research that are related not only to the items missing in the systematic process of construction of the models (see Table 1), but also with the absence of algorithms for estimating the parameters of models that use the innovations or past waste as entries in the models of neural networks in the same way as the autoregressive models, in order to be able to anticipate series that inherently continue processes of non-linear moving averages.

RQ3. What are the published studies presented a systematic approach, step by step, for the construction of the model?

The score associated with each study (Table 2), it was concluded that only 8% of new models explicitly addressed: the selection of the architecture, the determination of the complexity of the model, the selection of the relevant variables, the estimation of the parameters and the implementation and evaluation of the proposed model. Typically, the proposed models of the 2006 to 2016 presented a mathematical formulation and the selection of the architecture, the process of estimating parameters and the application to real data. However, it is necessary to carry out research on the following aspects:

1) Specifying criteria for the selection of the relevant variables.
2) Development of a methodology for determining the optimum architecture of the selected neural network model.
3) Development of methodologies for the evaluation of the model in terms of the capture of the main features of the series and its generalization.

Another important aspect here is the fact that these models are used as a reference for further studies, although the problems identified on your specification process have not been resolved.

RQ4. What are the outstanding problems to be solved in new proposed approaches?

In Table 2, column 3 to 10 presented the outstanding areas of research; they are identified with the letters P and N.

6. Conclusion

In this study we examined the most relevant published articles in the literature during the period 2006–2016. The survey focused on the proposed new models based on artificial neural networks for the prediction of non-linear time series. For each of the analyzed articles the existing problems that to be solved were discussed.

In general, it was observed that the models posed in the selected studies; do not completely satisfy a systematic procedure for the construction of an ANN model. The mathematical specification of the model and the explicit training definition procedure are partly or entirely found in the 17 selected studies. However, this does not happen with the other stages of the construction which must meet an ANN model. Likewise, it was concluded in the literature that there are no ANN models that explicitly consider the inclusion of MA terms, which seem to be present in many real time series.

Future studies should consider more data sources such as Google Scholar and Thomson Master Journals to reach more relevant researches. Also studying these researches should distinguish between the type of forecasting and if it is one-step or multi-step forecasting. For more advanced survey, forecasting using different types of computational intelligences techniques should be considered too.

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