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Optimisation of water demand forecasting by artificial intelligence with short data sets

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Irrigated agriculture is one of the key factors responsible for decreasing freshwater availability in recent years. Thus, the development of new tools which will help Irrigation District managers in their daily decision making process about the use of water and energy is essential. On the other hand, the new era of Big Data and information and communications technologies (ICT) has made it possible to have a larger amount of information available, leading to the development of new prediction tools. However, the quality and quantity of this information in many fields such as irrigated agriculture is limited. Consequently, the way in which the development of new predictive models is addressed must be reformulated. Thus, in this work, a new methodology to provide short-term forecasting of daily irrigation water demand when data availability is limited has been developed by coupling dynamic Artificial Neural Networks (ANN) architecture, the Bayesian framework and Genetic Algorithms (GA). The methodology was applied in the Bembézar MD Irrigation District (Southern Spain). The developed model improved the prediction accuracy by between 3% and 11% with respect to previous work. The best ANN model had a Standard Error Prediction (SEP) and a determination coefficient (R^2) of 8.7% and 96%, respectively. The accuracy of the model developed makes it a powerful tool for the daily management of irrigation districts.

1. Introduction

In recent decades, freshwater availability has been dramatically reduced because of the constant increase of agricultural and human water demands and climate change. On the other hand, in many irrigated areas, the old water distribution channels have been replaced by new pressurised irrigation networks which operate on-demand. Consequently, the uncertainty associated with irrigation water demands and the water costs in many irrigation districts has been raised (Fernández García, Rodríguez Díaz, Camacho Poyato,

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Montesinos, & Berbel, 2014) causing serious challenges in the daily management of irrigation districts. Therefore, new tools to reduce the uncertainty associated with water demand and to optimise the daily irrigation district management is essential to ensure the future of irrigated agriculture.

The information and communications technologies (ICT) revolution as well as the development of new sensors, in recent years, has allowed robust information to be recorded every second or even millisecond. This evolution in sensors and ICT suggests that there are opportunities for the development of Big Data and new management tools based on predictions and Artificial Intelligence (AI). In addition, the Cloud computing development and virtual storage has reduced the storage cost of Big Data (Bin & Xin, 2013). Therefore, in the Big Data era, data as the indispensable raw materials of information economy have penetrated into every sector of the economy (Liu, Bao, & Xu, 2014). However, data availability in irrigated agriculture fields is very poor in both quality and quantity. Thus, the development models based on these data cause serious problems in the daily decision-making process of the irrigation district managers.

Big Data and AI in the water management field have been used in probabilistic hydrology prediction (Zhang, Liang, Yu, & Zong, 2011), forecasting groundwater level (Shirmohammadi, Vafakhah, Moosavi, & Moghaddamnia, 2013), prediction of furrow irrigation infiltration (Mattar, Alazba, & Zin El-Abedin, 2015) and even prediction of filtered volume in micro-irrigation sand filters (Puig-Bargués, Duran-Ros, Arbat, Barragán, & Ramírez de Cartagena, 2012). However, there are very few prediction tools for daily water demand in pressurised distribution networks which are useful for the managers of the irrigation districts.

Pulido-Calvo and Gutiérrez-Estrada (2009) developed a daily water demand predictive model using Fuzzy Logic (FL) approach and Artificial Neural Networks (ANN). In that work, Genetic Algorithms (GA) were used to optimise the shape of fuzzy sets, the overlapping level of fuzzy sets and the fuzzy rules definitions but the architecture of the ANN was determined by trial and error. González Perea, Poyato, Montesinos, and Díaz (2015) developed an Artificial Neuro-Genetic Network (ANGN) to predict the daily irrigation demand in an irrigation district. In that work, the parameters that define the ANN architecture as well as the ANN generalisation to avoid the model overfitting were optimised by GA. Results showed that the predictive model made substantial errors when it would be more useful for managers (during periods of higher and lower water demand) because of the way that the ANN was generalised. The methodology developed by González Perea et al. (2015) had high data requirements for the ANN learning process while usually water users' associations do not have long datasets of water consumption available. Thus, that methodology represents a major constraint in situations of low data availability causing wrong generalisations of the ANN. Nevertheless, there are other algorithms based on Bayesian framework (MacKay, 1992) which automatically sets the regularisation parameters of the ANN generalisation reducing the effective parameters of the ANN and so the amount of data required during the training process. Thus, in this work, a new methodology to provide the short-term forecasting of daily irrigation water demand has been developed by coupling dynamic ANN architecture, the Bayesian framework and GAs. The developed model was tested in a real irrigation district in Southern Spain and the obtained results were compared to previous research.

2. Methodology

2.1. *Artificial Neural Networks and the Bayesian training framework*

The performance of a predictive system is conditioned by factors or parameters such as the type of ANN used, the ANN architecture (number of layers, neuron number of each layer, number of input variables, …), transfer function of each layer, training functions and the way that the ANN is generalised. In this work, Multilayer Perceptron Network (MLP) (Fig. 1) has been used as ANN due to its adaptability to many engineering problems. MLP consists of three main layers: input, hidden and output layer. The number of input and output variables of the model determines the number of neurons of the input and output layers. MLP can be made up by one or more hidden layers. Both the number of hidden layers and the number of neurons of these layers depend on the problem being tackled. In most studies, these two variables are established by trial and error leading to predictive models with poor generalisation. In this paper, both parameters have been optimised by GA. Thus, a dynamic ANN architecture has been implemented in the GA to obtain the optimum values of the ANN architecture.

Each neuron of the MLP can only transfer information from its layer to the next one by a transfer function (TF). The TF determines the degree of excitation of each layer. In this work, the TF assigned to each layer was optimised by GA. Each neuron (Fig. 1) is linked from a previous layer to the next one by a synaptic weight (w).

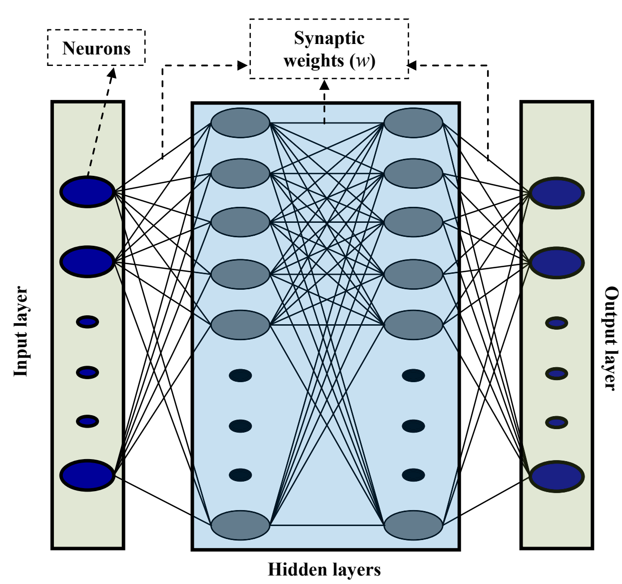

Fig. 1 – Multi-layer perceptron neural network.

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