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Using self-adaptive evolutionary algorithm to improve the performance of an extreme learning machine for estimating soil temperature

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ABSTRACT

In this study, the self-adaptive evolutionary (SaE) agent is employed to structure the contributing elements to process the management of extreme learning machine (ELM) architecture based on a logical procedure. In fact, the SaE algorithm is utilized for possibility of enhancing the performance of the ELM to estimate daily soil temperature (*ST*) at 6 different depths of 5, 10, 20, 30, 50 and 100 cm. In the developed SaE-ELM model, the network hidden node parameters of the ELM are optimized using SaE algorithm. The precision of the SaE-ELM is then compared with the ELM model. Daily weather data sets including minimum, maximum and average air temperatures (T_{min}, T_{max} and T_{avg}), atmospheric pressure (P) and global solar radiation (R_S) collected for two Iranian stations of Bandar Abbas and Kerman with different climate conditions have been utilized. After primary evaluation, T_{min}, T_{max} and T_{avg} are considered as final inputs for the ELM and SaE-ELM models due to their high correlations with *ST* at all depths. The achieved results for both stations reveal that both ELM and SaE-ELM models offer desirable performance to estimate daily *ST* at all depths; nevertheless, a slightly more precision can be obtained by the SaE-ELM model. The performance of the ELM and SaE-ELM models are verified against genetic programming (GP) and artificial neural network (ANN) models developed in this study. For Bandar Abbass station, the obtained mean absolute bias error (MABE) and correlation coefficient (R) for the ELM model at different depths are in the range of 0.9116–1.5988 °C and 0.9023–0.9840, respectively while for the SaE-ELM model they are in the range of 0.8660–1.5338 °C and 0.9084–0.9893, respectively. In addition, for Kerman Station the attained MABE and RMSE for the ELM model vary from 1.6567 to 2.4233 °C and 0.8661 to 0.9789, respectively while for the SaE-ELM model they vary from 1.5818 to 2.3422 °C and 0.8736 to 0.9831, respectively.

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1. Introduction

The information of soil temperature is particularly important in various scientific researches such as hydrology, meteorology and atmospheric sciences (Jackson et al., 2008). Soil temperature plays a remarkable role in analyzing the eco-environmental conditions and climate change of the region (Wu et al., 2013). Soils gain heat energy mostly from the sun. Thus, when the solar radiation intensity and also number of days and seasons vary the level of absorption and loss of radiant energy for soils change (Bilgili, 2012). Since the ground has a slow rate of heat transportation and a high heat storage capacity, its temperature variations show slow trends. Owing to the low thermal conductivity of ground, the soil can release heat to the atmosphere during the cooling periods. In contrast, throughout the heating periods or summer season the soil absorbs heat from the atmosphere which can be utilized efficiently in the winter season. This cycle between the soil and the atmosphere during the year indicate that soil is a desirable source of a thermal energy potential (Bilgili, 2010; Talaee, 2014). In the colder period, the soil is warmer than the ambient air and vice versa in the warmer period. Therefore, soil temperature is a significant meteorological parameter in the application of ground source heat pump, solar energy applications such as passive heating for buildings as well as computation of the heat losses from the buildings (Mihalakakou, 2002; Bilgili, 2010).

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Moreover, soil temperature data at different depths is useful in ecological applications and agricultural managements (Kätterer and Andrén, 2009). Soil temperature is an important element in controlling the interactive processes between the ground and the atmosphere. It identifies the type and rate of physical, chemical, biological and microbiological interactions in the soil (Ghuman and Lal, 1989; Tenge et al., 1998; Zhang et al., 2001; Hu et al., 2002). Soil temperature is influential in diffusion of nutrients in soil and their uptake by plants. In the soil profile, the decomposition and movement rates of nutrients chemicals are considerably influenced by soil temperature variations (Jebamalar et al., 2012).

Nevertheless, the measured soil temperature data at ground surface and various depths are rarely available for many locations. Therefore, developing theoretical approaches for predicting soil temperature at different depths using other exiting data such as meteorological parameters would be of indispensable significance (Mihalakakou, 2002; Paul et al., 2004). Soil temperature and other climatic parameters have complex inter-relationships. Such complex problems can be efficiently solved using neutral network (NN) and nature-inspired metaheuristic algorithms such as monarch butterfly optimization (Wang et al., 2015), earthworm optimization algorithm (Wang et al., in press), krill herd algorithm (G.G. Wang et al., 2014), harmony search algorithm with cuckoo search (Wang et al., 2016).

NN has been broadly employed in different engineering fields. Application of this method provides the possibility of solving complex nonlinear problems, which cannot be solved easily by classic numerical and analytical methods. Several algorithms can be used to train NN including the Gradient Descent (GD) (Sudheer and Mathur, 2012).

The major disadvantage of NNs is their learning time requirement. Huang et al. (2004) proposed an algorithm for a single-layer feedforward neural network (SLFN) recognized as extreme learning machine (ELM). The ELM algorithm is capable of reducing the required time to train a NN (Huang et al., 2004).

In fact, by using the ELM, the learning becomes very fast and produces good generalization performance (Huang et al., 2004; Liang et al., 2006), because the ELM simplifies the training processes by selecting the randomly parameters. The ELM has a faster learning speed than traditional algorithms such as the back-propagation (BP) (Huang et al., 2015). The ELM also has a better performance since it enjoys the ability of obtaining the smallest training error and norm of weights (Bartlett, 1998). As a result, the ELM algorithm has been employed in various scientific fields such as time-series prediction, pattern recognition and classification (Ghouti et al., 2013; Zhao et al., 2013; Nian et al., 2014; Wang and Han, 2014; D.D. Wang et al., 2014; Yu et al., 2014; Samat et al., 2014; Wong et al., 2015; Tavares et al., 2015).

Nevertheless, due to the fact that the network hidden node parameters in ELM are selected in a random manner, the model trained by ELM is random. Therefore, the self-adaptive evolutionary extreme learning machine (SaE-ELM) can be used to optimize the hidden node parameters and hidden node biases (Cao et al., 2012; Das et al., 2013). This provides a higher compact network size than the ELM and also enhances the generalization performance of the ELM.

In this research, the self-adaptive evolutionary (SaE) algorithm is used to assess whether it can improve the performance of ELM technique for estimating daily soil temperature. In the SaE-ELM model, the network hidden node parameters of the ELM are optimized using SaE algorithm. The capability of SaE-ELM model is compared with ELM. To fulfill this objective, daily weather data of two Iranian stations of Bandar Abbas and Kerman which enjoy different climate conditions have been used as case study. The simulation is conducted to estimate daily soil temperature at six depths of 5, 10, 20, 30, 50 and 100 cm, and afterwards the estimated values are compared with the measured data using reliable statistical indicators.

2. Related works

In recent years, the artificial intelligence techniques have been widely employed for soil temperature prediction and modeling at various depths. In this section, some of the previous studies are reviewed briefly.

Mihalakakou (2002) employed two models: (1) an analytical deterministic model based on heat conduction and energy balance equations and (2) an intelligent model based on artificial neural network (ANN) technique for estimating daily and annual soil temperature in Athens and Dublin.

The obtained results showed that ANN can be used effectively to predict soil temperature; however, the analytical model provides more accuracy. Bilgili (2010) utilized linear and non-linear regressions as well as ANN techniques to predict monthly soil temperature at 5 different depths based upon several parameters for Adana, Turkey. They found that soil temperature can be predicted favorably using the parameters of atmospheric temperature and pressure as well as global solar radiation. Also, ANN is more efficient than the regression methods. Ozturk et al. (2011) developed feed-forward ANN models to estimate soil temperature at five depths of 5, 10, 20, 50 and 100 cm in 66 locations of Turkey. They utilized different geographical and meteorological parameters as inputs. They found that the developed models are capable to estimate soil temperature with good accuracy. Tabari et al. (2011) applied a multilayer perceptron (MLP) based ANN model and a multivariate linear regression (MLR) method for estimating daily soil temperature at 6 different depths in an arid region of Iran. The attained results showed that ANN provides superiority over the MLR method. Also, the average ambient temperature and relative humidity are the most significant elements to estimate soil temperature at all depths. Jebamalar et al. (2012) developed an ANN model trained by back propagation algorithm to predict soil temperature at 10 cm and 20 cm in a location in India. They tested the capability of the ANN model and found that it can be a favorable model to predict soil temperature with high accuracy. Napagoda and Tilakaratne (2012) used nonlinear auto regressive neural network with exogenous input (NARX) models and feedforward neural network (FNN) models to forecast weekly soil temperature at 5 cm and 10 cm depths at Bathalagoda area in Seri Lanka. They found that more accuracy can be achieved by NARX models so that they can be appropriate models for soil temperature prediction in the considered location. Mazou et al. (2012) employed time-delay neural network technique to predict soil temperature at different depths in Athens, Greece. The developed model utilized recurrent neural networks with feedback loop that consisted of time-delay elements. They found the model has a good prediction capability. Bilgili (2012) developed an ANN model for predicting monthly soil temperature at different depths of 5, 10, 20, 50 and 100 cm at 8 locations in the Aegean region of Turkey. It was found that the developed model can be utilized successfully to predict the soil temperature in the considered locations. Bilgili et al. (2013) applied multiple nonlinear regression analysis and ANN approach to predict monthly soil temperature at 5 depths for different locations of Turkey using only soil temperature data of neighboring stations. Their findings showed that the ANN model offers precise prediction of soil temperature. Wu et al. (2013) developed an ANN-based model to predict monthly mean soil temperature at 10 cm depth for a large area with complex train. They compared the capability of the ANN with multi linear regression and found that ANN offers much higher performance for prediction of soil temperature. Talaee (2014) estimated daily soil temperature

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