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Prediction of wastewater treatment plant performance based on wavelet packet decomposition and neural networks

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Abstract

In this paper, an intelligent wastewater treatment plant model is developed to predict the performance of a wastewater treatment plant (WWTP). The developed model is based on wavelet packet decomposition, entropy and neural network. The data used in this work were obtained from a WWTP in Malatya, Turkey. Daily records of these WWTP parameters over a year were obtained from the plant laboratory. Wavelet packet decomposition was used to reduce the input vectors dimensions of intelligent model. The suitable architecture of the neural network model is determined after several trial and error steps. Total suspended solid is one of the measures of overall plant performance so the developed model is used to predict the total suspended solid concentration in plant effluent. According to test results, the developed model performance is at desirable level. This model is an efficient and a robust tool to predict WWTP performance.

Keywords: Wavelet packet decomposition; Entropy; Wastewater treatment plant; Total suspended solid

1. Introduction

In recent years, intelligent modeling studies related to WWTP have become popular because of the rising concern about environment. The developments in intelligent methods make them possible to use in complex systems modeling. Intelligent modeling was firstly used to increase the robustness of existing models but now it is used to obtain new models.

Complex mathematical models are including many biochemical processes. Yet, due to the scarcity of measured data, it is almost impossible to obtain reliable estimates of unknown dynamical parameters. Therefore, either simpler, manageable models are needed. So considerable efforts have been expended to change or modify the traditional wastewater treatment processes (Müller, Noykova, Gyllenberg, & Timmer, 2002). Improper operation of a WWTP may bring about serious environmental and public health problems, as its effluent to a receiving water body can cause or spread various diseases to human beings. A better control of a WWTP can be achieved by developing robust models for predicting the plant performance based on past observation so certain key parameters. However, modeling a WWTP is a difficult task due to the complexity of the treatment processes. The complex physical, biological and chemical processes involved in wastewater treatment process exhibit nonlinear behaviors which are difficult to describe by linear mathematical models (Hamed, Khalafallah, & Hassanien, 2004).

In the last decade, many studies were realized in wastewater treatment based on intelligent methods. These researches are related to modeling WWTP. These researches are about predictions of WWTP parameters, process control of WWTP, estimating WWTP output parameters characteristics. Some of these studies based on intelligent methods are as follows. A novel approach on the basis of ANN model that was designed to provide better predictions of nitrogen contents in treated effluents was reported by

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Chen, Chang, and Shieh (2003). Total suspended solid (TSS) is an indication of plant performance. A simple prediction models based on neural network for TSS was demonstrated in Belanche, Valdés, Comas, Roda, and Poch (2000). To develop a neural network model to predict long term fouling of nanofiltration membranes that are used to purify contaminated water supplies was demonstrated in Shetty and Chellam (2003). ANN-based models for prediction of biological oxygen demand (BOD) and suspended solid (SS) concentrations in plant effluent were presented in Hamed et al. (2004). A model based on ANN was developed for evolution of the pollutant concentration during irradiation time under various conditions was presented in Göb et al. (1999). The coagulation-flocculation is a major step in the drinkable water treatment process allowing the removal of colloidal particles. ANN predictor of coagulant dosage in order to facilitate process operation was reported in Gagnon, Grandjean, and Thibault (1997).

A simplified hybrid neural net approach was applied for the modeling and subsequent analysis of a chemical waste water treatment plant in Mizushima, Japan to reduce the occurrences of overflow in the clarifier caused by filamentous bulking and thereby increase waste water treatment capacity was presented in Miller, Itoyama, Uda, Takada, and Bhat (1997). The soft-sensing method based on neural networks was proposed in order to detect on-line wastewater treatment quality parameters. In that study WWT technique was analyzed systematically. The parameters which can be detected on-line were taken as the secondary variables. The parameters which can not be detected on-line were taken as the primary variables. Back propagation (BP) NN for soft-sensing is proposed and trained using the testing data of practical treatment process. The simulation results were showed that the soft-sensing system of wastewater treatment based on BPNN can correctly estimates the quality parameters on real time (Wan-liang & Min, 2002). In another study, neural network models were used to model alum dosing of southern Australian surface waters was presented in Maier, Morgan, and Chow (2004).

In this paper, wavelet packet analysis, entropy and NN are combined to extract the features from processed data for estimating TSS as output quality parameter.

The paper is organized as follows. In Section 2, we review some basic properties of used methods, wavelet packet decomposition, NNs. The intelligent model and entropy is described in Section 3. This method enables reduction of the data size and make model efficient. The effectiveness of the proposed model is demonstrated in Section 4. Finally Section 5 presents discussion and conclusions.

2. Preliminaries

In this section, the theoretical foundations for the intelligent modeling used in the presented study are given in the following subsections.

2.1. Wavelet transform

Wavelet transforms are finding inverse use in fields as diverse as telecommunications and biology. Because of their suitability for analyzing non-stationary signals, they have become a powerful alternative to Fourier methods in many medical applications, where such signals abound (Daubechies, 1998). The main advantages of wavelets is that they have a varying window size, being wide for slow frequencies and narrow for the fast ones, thus leading to an optimal time-frequency resolution in all the frequency ranges. Furthermore, owing to the fact that windows are adapted to the transients of each scale, wavelets lack the requirement of stationary.

A wavelet expansion is Fourier series expansion, but is defined by a two-parameter family of functions. It can be defined as follows:

$$f(x) = \sum_{i,j} c_{i,j}\psi_{i,j}(x), \tag{1}$$

where i and j are integers, the functions $\psi_{i,j}(x)$ are the wavelet expansion functions and the two-parameter expansion coefficients $c_{i,j}$ are called the discrete wavelet transform (DWT) coefficients of $f(x)$. The coefficients are given by:

$$c_{i,j} = \int_{-\infty}^{+\infty} f(x)\psi_{i,j}(x). \tag{2}$$

The wavelet basis functions can be computed from a function $\psi(x)$ called the generating or mother wavelet through translation and dilation:

$$\psi_{i,j}(x) = 2^{-i/2}\psi(2^{-i}x - j), \tag{3}$$

where j is the translation and i the dilation parameter. Mother wavelet function is not unique, but it must satisfy a small set of conditions. One of them is multi-resolution condition and related to the two-scale difference equation;

$$\phi(x) = \sqrt{2}\sum_k h(k)\phi(2x - k), \tag{4}$$

where $\phi(x)$ is scaling function and $h(k)$ must satisfy several conditions to make basis wavelet functions unique, orthonormal and have a certain degree of regularity. The mother wavelet is related to the scaling function as follows,

$$\psi(x) = \sqrt{2}\sum_k g(k)\phi(2x - k), \tag{5}$$

where $g(k) = (-1)^k h(1 - k)$. At this point, if valid $h(x)$ is available, one can obtain $g(x)$. Note that h and g can be viewed as filter coefficients of half band low pass and high pass filters, respectively. J-level wavelet decomposition can be computed with Eq. (6) as follows:

$$\begin{aligned} f_0(x) &= \sum_k c_{0,k}\phi_{0,k}(k) \\ &= \sum_k \left(c_{J+1,k}\phi_{J+1,k}(x) + \sum_{j=0}^{J} d_{j+1,k}\psi_{j+1,k}(x) \right), \end{aligned} \tag{6}$$