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Journal of Electrical Systems and Information Technology 1 (2014) 129–143

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Fuzzy dynamic modelling and predictive control of a coagulation chemical dosing unit for water treatment plants

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Received 12 June 2014; accepted 11 August 2014
Available online 19 August 2014

Abstract

In this paper, a fuzzy model predictive control (FMPC) strategy is proposed to regulate the output variables of a coagulation chemical dosing unit. A multiple-input, multiple-output (MIMO) process model in form of a linearised Takagi–Sugeno (T–S) fuzzy model is derived. The process model is obtained through subtractive clustering from the plant's data set. The MIMO model is described by a set of coupled multiple-input, single-output models (MISO). In the controller design, the T–S fuzzy model is applied in combination with the nonlinear model predictive control (MPC) algorithm. The results show that the proposed controller has good set-point tracking when compared with nonlinear MPC and adequate disturbance rejection ability required for efficient coagulation control and process optimisation in water treatment operations.

Keywords: Water treatment plants; Chemical dosing unit; Fuzzy dynamic model; Fuzzy model predictive control; Linearisation; Optimisation

1. Introduction

Coagulation process in water treatment operations involves removal of colloidal and suspended particles from raw waters through the addition of optimum quantity of relevant chemical reagents under a rapid mixing condition. Many water purification plants add coagulants and pH adjustment chemicals to raw waters in a rapid mixing tank or pipe to facilitate the coagulation process. The key issue with coagulation process is to control the quantity of chemical dosages that are added to the raw water influents taking into considerations variations in water quality and demands. When coagulation control is inadequate, the plant fails to satisfy water quality standards, expensive chemicals are wasted and less efficient filtration operation are performed due to unsettled flocs formation (Adgar et al., 2005; Valentin et al., 1999). In order to overcome these aforementioned problems, effective coagulation control is imperative for good portable water production and reduction in the total operational cost of the plant.

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Peer review under responsibility of Electronics Research Institute (ERI).

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jesit.2014.08.001

Coagulation control in water treatment plants is inherently difficult due to sudden changes in water quality and complex physicochemical reactions involved in the process. Many control strategies have been proposed in the literature to control the coagulant dosage system, but their works differ based on their process models, control objectives and methods. Evans et al. (1998) proposed a feedforward controller based on adaptive neuro-fuzzy network for Huntington water treatment plant in North West England. In Baxter et al. (2002), the integration of artificial neural network models with the supervisory control and data acquisition (SCADA) system through a number of process optimisation interfaces is presented in accordance with variations in influent water quality parameters.

In Fletcher et al. (2002), a feedforward coagulation control is developed using models based on nonlinear transformation of variables, multi-layer perceptron (MLP) and radial basis function (RBF) networks to improve the system in conjunction with a proportional controller. In another study reported by Adgar et al. (2005), the authors investigated the application of feedback control with decoupler on coagulation process in a twin pilot plant using streaming current detector and pH sensor to improve the existing manually flow-proportional control strategy. Analysis of the data collected during experiments on the pilot plant demonstrated that there is strong relationship and interaction between the streaming current detector and pH sensor measurements.

Model predictive control is widely used and accepted for effective and efficient process control in industries. The main objective of MPC strategy is to keep the output variables close to their reference trajectories taking into consideration the operating constraints (Morari and Lee, 1999). Linear model predictive control uses linear model to predict the system dynamics. It is effective for systems with only linear characteristics. However, nonlinear systems are poorly represented by linear models. Therefore, nonlinear model predictive control (NMPC) using nonlinear predictive model and optimisation methods are recommended for nonlinear systems and control applications.

The necessity to produce drinking water safe for public consumption has led to imposition of strict regulations on water treatment plants. It is therefore important to have in place an optimizing control with constraints handling capability to comply with the standards laid down by the regulatory bodies. The application of linear MPC has been studied on the coagulant dosage system for water treatment plants (Paz et al., 2009). The author used a linear model of the system for their study. It is focussed on a SISO model rather than solving nonlinear and multivariable control problem. The authors do not consider the effect of pH adjustment on the coagulation control and nonlinear behaviour of the system.

In this paper, fuzzy model predictive control is considered and proposed to control the surface charge (SC) and pH values of the effluent stream from the coagulation chemical dosing unit of a water treatment plant. Generally, accurate modelling of nonlinear multivariable system using mechanistic modelling technique is challenging. However, with the application of intelligent methods such as fuzzy modelling, an easy and effective model could be developed. Fuzzy identification approach based on subtractive clustering is proposed to develop a fuzzy model of a chemical dosing unit from a set of data collected from a water treatment plant in South Africa. The linearised Takagi–Sugeno model is applied in the development of FMPC for the unit. Simulation tests are carried out to determine the suitability of the proposed control strategy for the coagulation control in water treatment operations.

The paper is organised as follows. Section 2 provides the description of the Rietvlei water treatment plant. The fuzzy modelling and identification technique and main concepts of fuzzy MPC are discussed in this section. The simulation setup, model validation, simulation results and analysis are discussed in Section 3. Section 4 draws some conclusions from the study.

2. Materials and methods

2.1. Description of Rietvlei water treatment plant

Rietvlei water treatment plant in the City of Tshwane, South Africa has a production capacity of about 40 million litres per day. The plant draws raw waters from Rietvlei dam. A pumping station and transport system are available to lift waters from the dam to the treatment plant located about 200 m away from it. Raw waters flow through the intake pipe into the chemical dosing unit. The volume of water abstracted is used to determine the quantity of chemical reagents required for the coagulation process.

Raw water inlet valve is placed after the flowmeters to control the quantity of water flowing into the plant. Fig. 1 illustrates the coagulation chemical dosing unit of Rietvlei water treatment plant. It contains a concrete mixing tank with inlet and outlet channels. There are two-pairs of metering pumps that are used for dosing coagulation chemicals into