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An improved sampling strategy based on trajectory design for application of the Morris method to systems with many input factors

M.V. Ruano [a,*], J. Ribes [a], A. Seco [a], J. Ferrer [b]

[a] Dep. Enginyeria Química, Universitat de València, Avinguda de la Universitat, s/n 46100 - Burjassot (València), Spain
[b] Instituto de Ingeniería del Agua y Medio Ambiente, Universidad Polotécnica de Valencia, Camino de Vera s/n., 46022 Valencia, Spain

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ABSTRACT

In this paper, a revised version of the Morris approach, which includes an improved sampling strategy based on trajectory design, has been adapted to the screening of the most influential parameters of a fuzzy controller applied to WWTPs. Due to the high number of parameters, a systematic approach has been proposed to apply this improved sampling strategy with low computational demand. In order to find out the proper repetition number of elementary effects of each input factor on model output (EE_i) calculations, an iterative and automatic procedure has been applied. The results show that the sampling strategy has a significant effect on the parameter significance ranking and that random sampling could lead to a non-proper coverage of the parameter space.

1. Introduction

WWTP models are used for many applications/purposes including plant design, optimisation and control. It is generally accepted that the modelling and simulation of WWTPs represents a powerful tool for control system design and tuning. However, model predictions are not free from uncertainty as these models are an approximation of reality (abstraction), and are typically built on a considerable number of assumptions. In this regard, sensitivity analysis provides useful information for the modellers as this technique attempts to quantify how a change in the model input parameters affects the model outputs. Different strategies have been applied in the literature (see for instance, Saltelli et al., 2000; Shahsavani and Grimvall, 2011; Nossent et al., 2011), which are typically classified into two main categories: global sensitivity analysis, where a sampling method is taken and the uncertainty range given in the input reflects the uncertainty in the output variables (Monte Carlo analysis; Fourier Amplitude Sensitivity Test (FAST), variance-based sensitivity analysis, Morris Screening (1991)); and local sensitivity analysis, which is based on the local effect of the parameters on the output variables (Weijers and Vanrolleghem, 1997; Brun et al., 2002).

The Morris method is a one-factor-at-a-time (OAT) method of sensitivity analysis, which calculates the so-called elementary effects, EE_i, of each input factor on model outputs. While the EE_i is in itself a local measure of sensitivity, this drawback is overcome by repeating EE_i calculations in the input space domain using Morris' efficient random sampling strategy, which is obtained via a trajectory based design (see for instance, Saltelli and Annoni, 2010). The analysis of the distribution of elementary effects, F_i, of each input factor will assess the relative importance of the input factors, which approximates well to a global sensitivity measure. One key issue of this approach is that the sampling matrix is randomly generated. This random sampling strategy can be characterised by a poor representation of the sampling space, which can lead to a non-proper screening of the non-influential parameters. For this reason, Campolongo et al. (2007) suggested a revised version of the elementary effects method, where an improved sampling strategy is defined by maximising the distances between the final trajectories (r) selected. However, this improved sampling strategy was found to be unfeasible for large models due to the high computational demand required to solve the resulting combinatorial optimisation problem (Campolongo et al., 2007). Apart from trajectory based designs, other sampling strategies have recently been assessed for screening purposes, such as the radial based design (Saltelli et al., 2010; Campolongo et al., 2011). With this approach, the EE of each parameter is evaluated at the same initial point in the parameter space, but with a different step size. This design differs

* Corresponding author. Tel.: +34 96 387 70 07x76131; fax: +34 96 354 48 98.
E-mail addresses: m.victoria.ruano@uv.es (M.V. Ruano), josep.ribes@uv.es (J. Ribes), aurora.seco@uv.es (A. Seco), jferrer@hma.upv.es (J. Ferrer).

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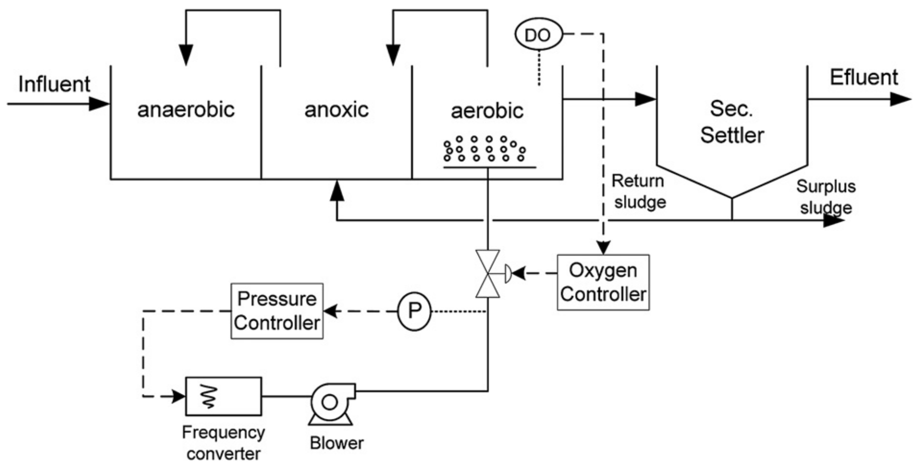

Fig. 1. Flow diagram of the control system applied to a modified UCT process.

from trajectory based designs, where the EE of each parameter is evaluated with the same step size but at different initial points in the parameter space.

Fuzzy logic based controllers have been successfully applied on wastewater treatment processes (see e.g. Ferrer et al., 1998; Serralta et al., 2002), since fuzzy sets theory offers an effective tool for the development of intelligent control systems (Zhu et al., 2009). Fuzzy control algorithms can be used to create transparent controllers that are easy to modify and extend because the fuzzy rules are written in the language of process experts and operators (Yong et al., 2006). Although these control systems have been shown to be more robust than classical controllers (Manesis et al., 1998; Traoré et al., 2005), they usually contain quite a number of parameters, which complicates their calibration. So far, these control systems have been tuned by trial and error methods, based on technical knowledge of process and controller performance (Chanona et al., 2006). Whatever optimisation method is applied, the fine-tuning of these controllers requires a previous selection of the most important parameters to be adjusted in each particular application. A systematic approach for the fine-tuning of fuzzy controllers based on model simulations was proposed by Ruano et al. (2010) and it employs three statistical methods: (i) Monte-Carlo procedure: to find proper initial conditions, (ii) identifiability analysis: to find an identifiable parameter subset of the fuzzy controller based on local sensitivity analysis and (iii) minimisation algorithm. However, this methodology is based on local sensitivity analysis, and then requires an iterative procedure to confirm that the identifiable parameter subset does not depend on the local point in the parameter space where the identifiability study has been carried out. A global sensitivity analysis based on the Morris approach was proposed to overcome the problem of selecting the proper initial point in the parameter space (Ruano et al., 2011). However, the random sampling strategy of this approach could lead to a non-proper screening of the non-influential parameters (Campolongo et al., 2007). In this study, the revised version of the Morris approach proposed by Campolongo et al. (2007) has been applied to screen out the most influential parameters of a fuzzy logic based aeration control system for WWTPs. Due to the high number of parameters, a systematic procedure has been proposed to overcome the high computational demand of this approach. Hence, an improved sampling strategy based on trajectory design is proposed for the application of the Morris method to systems with many input factors. Although this procedure does not guarantee that the final trajectories (r) selected present the global maximum distances between them, these distances are at least locally maximised. Finally, the results obtained with the application of the improved sampling strategy are compared with the ones obtained with a random sampling strategy.

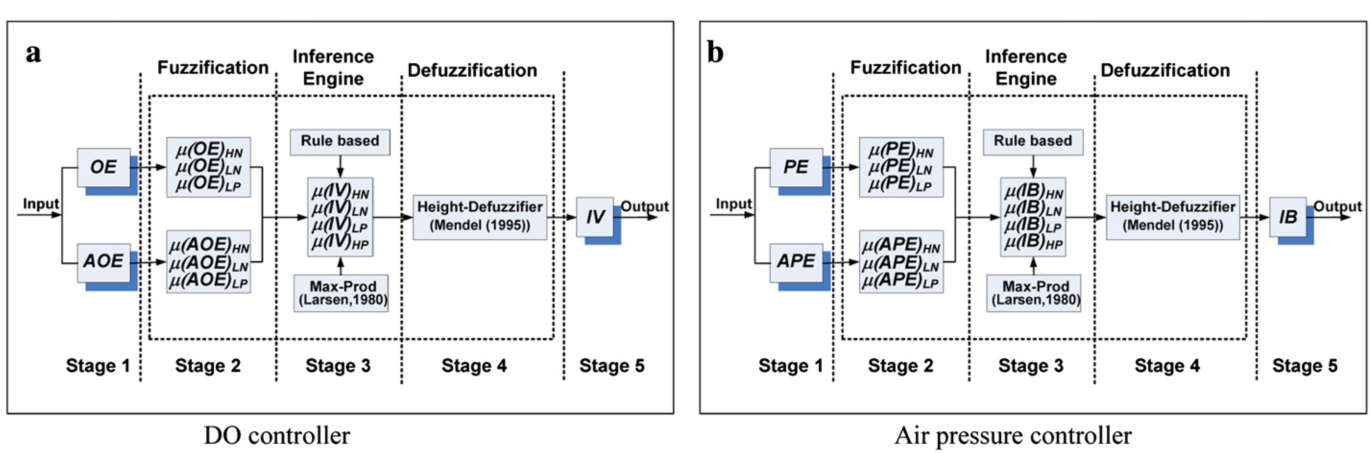

Fig. 2. Fuzzy control stages for the two controllers: (a) dissolved oxygen controller; and (b) air pressure controller.