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A novel robust liquid level controller for coupled-tanks systems using artificial hydrocarbon networks

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ABSTRACT

This paper proposes a robust liquid-level controller for coupled-tanks systems when dealing with variable discharge rates at the secondary tank, based on a hybrid fuzzy inference system that uses artificial hydrocarbon networks at the defuzzification step, so-called fuzzy-molecular control. The design methodology of the proposed controller is presented and discussed. In addition, a case study was run over the CE105 TecQuipment coupled-tanks system in order to implement and validate the fuzzy-molecular controller proposed in that work. A comparative evaluation with the proposed controller, a conventional PID controller specifically designed for this system and a QFT robust controller, was done. Also, a performance evaluation in terms of robustness, reference-tracking in a fixed operating point and reference-tracking in a variable operating point on-the-fly was run and analyzed. Results conclude that the proposed fuzzy-molecular controller deals with uncertainty and noise, can handle dynamics in operating point, a model of the plant is not required, and it is easy and simple to implement in comparison with other controllers in literature. To this end, the proposed fuzzy-molecular liquid-level controller inherits characteristics from fuzzy controllers and artificial hydrocarbon networks in order to implement an advanced robust and intelligent control system.

1. Introduction

Coupled-tanks systems are widely used in many industries. They are occupied in processes where fluids have to be stored in tanks and then transferred to other tanks as required; maintaining some values, such as a specific height. For example, applications of liquid level control approaches in coupled-tanks include: petrochemical industries, paper making, water treatment, food processing, beverage industries, pharmaceutical, and so forth (Abbas, Asghar, & Qamar, 2012; Holic & Vesely, 2011; Pan, Wonga, Kapilaa, & de Queiroz, 2005; Singh, Mukherjee, & Nikolaou, 2014). However, these systems require efficient liquid level controllers, due to the necessity of pumping the liquid stored in a primary tank to a secondary tank that are actually coupled together (see Fig. 3). In particular to coupled-tanks systems, one of the main problems in liquid level controllers considers the failure of them for reference-tracking due to variations of parameters in the system like time varying of discharge rates in tanks (e.g. variations in valve opening), falling in a dynamic set point.

In that sense, liquid level regulation in coupled-tanks systems can be handled using different control schemes. Literature and industry distinguish these control approaches as: fixed-gain controllers, predictive controllers, robust controllers, and intelligent controllers (Abbas et al., 2012; Benayache & Castelain, 2009; Benayache, Mahmoud, Chrifi-Alaoui, Bussy, & Castelain, 2009; Holic & Vesely, 2011; Pan et al., 2005; Tahir, Iqbal, & Mustafa, 2009). However, literature reports that fixed-gain controllers are inadequate when parameters of coupled-tanks systems are time varying and disturbances are present (Abbas et al., 2012; Liang, 2011). In any case, the PID controller is the most used strategy in coupled-tanks systems (Holic & Vesely, 2011).

For instance, predictive controllers are designed for calculating future control signals that minimizes a cost function defined over a prediction horizon (Khalid & Kadri, 2012). Several examples of this kind of control systems can be found, such as: the generalized predictive control (GPC), the most popular model predictive method (Clarke, Mohtadi, & Tuffs, 1987; Khalid & Kadri, 2012); or, the linear discrete-time model predictive control (DMPC) for multiple-input and multiple-output (MIMO) coupled-tanks systems (Khalid & Kadri, 2012). Recently, Khalid and Kadri (2012) use a linear model predictive control (MPC) based on Laguerre functions for determining the path of the state space model of the plant and minimizing perturbances. Alternately, robust controllers can deal with uncertainties,

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disturbances and time-varying systems (Abbas et al., 2012; Khan & Spurgeon, 2006). Sliding mode control (SMC) is the most common robust control technique that has been implemented for coupled-tanks systems for overcoming disturbances and noise (Abbas et al., 2012). However, chattering is an effect of SMC that causes a problem when dealing with controlling coupled-tanks systems. In that way, Almutairi and Zribi (2006) implement SMC in coupled-tanks system for liquid level using one static and dynamic sliding mode schemes in order to reduce the chattering problem. Other approaches of robust control are the second order sliding mode controller (SOSMC) developed for eliminating high frequency chattering due to high frequency switching (Benayache & Castelain, 2009; Benayache et al., 2009), and the second order sliding mode controller for MIMO systems (Khan & Spurgeon, 2006). In the work of Khan and Spurgeon (2006), a second order SMC is proposed, reducing the chattering problem but also improving the algorithm to produce a dynamic control without requiring the derivative of the sliding variable that typically needs an observer or peak detectors to inspect singular values.

On the other hand, intelligent controllers (IC) are characterized for using algorithms and methods inspired on human intelligence, and more recently, on natural intelligence (Yu, 2009). In that sense, fuzzy controllers and neural networks controllers have been well studied because they do not need an explicit mathematical model of the plant in order to be designed (Molina, Ponce, Ponce, Tello, & Ramirez, 2014; Yu, 2009). In addition, these intelligent controllers have proved to be very efficient when dealing with nonlinearities, uncertainty and noise (Liang, 2011; Ponce, Ponce, & Molina, 2013), positioning intelligent controllers over fixed-gain, predictive and robust controllers. For example, Lian, Marzuki, and Rubiyah (1998) proposes a hybrid neuro-fuzzy control system auto-tuning with genetic algorithms, providing an adaptive controller that handles noise, uncertainty and nonlinearities in liquid level coupled-tanks control systems. In (Li, Yi, & Zhao, 2008), a type-II fuzzy control system is proposed to handle high uncertainty improving the characteristics of intelligent controllers for coupled-tanks liquid level systems. This type-2 fuzzy control system includes a footprint of uncertainty in membership functions to deal with nonlinear relationships like disturbances and noise, also provides a dynamic operating point. However, type-II fuzzy controllers are difficult to implement and spend a lot of computational resources. Recently, literature reports hybrid intelligent and predictive or robust controllers in order to exploit characteristics from both schemes. For example, Aliasghary, Ghasemzadeh, Naderi, and Pourazar (2011) propose an alternative robust controller using intelligent methods developing a hybrid radial basis function neural networks with a sliding mode control scheme, aiming to solve the chattering problem and to handle low uncertainty and noise. Sarailoo, Rahmani, and Rezaie (2015) present a model predictive control using bees algorithm, a nature-inspired method, for minimizing a predefined cost function to find the best input signals subject to constrains and a model of the system.

From the above, liquid level coupled-tanks control system is still a challenging problem and a wide range of different controllers have been developed. In that way, this paper proposes a novel intelligent controller for a coupled-tanks system, based on a recent hybrid fuzzy inference system and artificial organic networks approach so-called fuzzy-molecular inference system (Ponce et al., 2013). This fuzzy-molecular inference system inherits characteristics from fuzzy inference systems (e.g. storage of knowledge from experts, dealing with uncertainty, linguistic variables) and artificial organic networks (e.g. packaging information in molecular units, organizing of information, dealing with aggresive uncertainty and noise), a learning method inspired on chemical organic compounds. In advance, fuzzy-molecular inference system can deal with uncertainty and under aggressive conditions of noise, with relative easiness of implementation (Molina et al., 2014; Ponce et al., 2013). Examples of fuzzy-molecular based controllers can be found in Molina et al. (2014) Ponce, Ibarra, Ponce, and Molina (2014a), Ponce et al. (2013, 2014b).

Thus, the objective of this work is to design, develop and implement an intelligent fuzzy-molecular liquid level controller for a coupled-tanks system in order to be robust in terms of any variation at the relative discharge rates of the second tank. In addition, this paper presents the implementation of the proposed controller in a case study over the CE105 TecQuipment coupled-tanks system. A comparative analysis with a conventional PID controller and a non-conventional quantitative feedback theory (QFT) controller, is presented and discussed. In a nutshell, the contribution of this work is summarized following:

- A novel intelligent controller based on fuzzy-molecular inference systems specifically for coupled-tanks systems is proposed.
- A simple but meaningful controller is described that overcomes uncertainty, noise and lack of robustness.
- A model of the plant is not required, so that the proposed controller can be easily generalized to other coupled-tanks systems, and it will not present chattering.
- A molecular partition of the output domain can be interpreted as linguistic units.
- At last, the proposed intelligent controller improves fuzzy controllers and performs better output response compared with conventional PID controllers and non-conventional controllers.

The rest of the paper is ordered as follows: Section 2 briefly describes artificial hydrocarbon networks and fuzzy-molecular inference systems. Then, Section 3 formalizes the proposed controller and its design. Later on, Section 4 describes the case study in which the proposal has implemented. Section 5 presents experimental results of the proposed controller. Lastly, Section 6 concludes this paper.

2. Fuzzy-molecular inference systems

This section introduces the notion of a fuzzy-molecular inference system (FMI), firstly proposed by Ponce et al. (2013). Roughly speaking, it is a hybrid fuzzy inference system (FIS) composed of a fuzzy partition at the input space of antecedents, and artificial hydrocarbon networks structures of consequences as part of fuzzy implications. Fig. 1 shows a fuzzy-molecular inference system (Ponce et al., 2013).

For full understanding, artificial hydrocarbon networks algorithm is introduced before a formal description of the fuzzy-molecular inference system.

2.1. Artificial hydrocarbon networks

Artificial hydrocarbon networks algorithm is based on a technique called artificial organic networks. It is a class of learning algorithms, inspired on chemical organic compounds, that is mainly characterized by packaging information in modules, so-called molecules

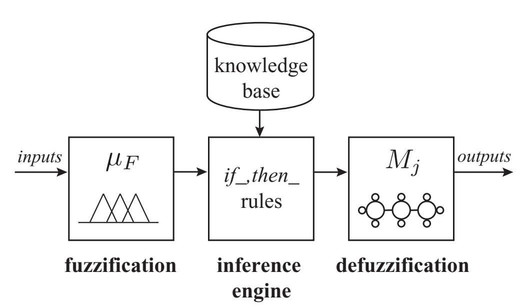

Fig. 1. Structure of a general fuzzy-molecular inference system: *fuzzification* is represented as a fuzzy partition of the input space, and *defuzzification* is composed of a molecular-based structure.

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