Applied Soft Computing 48 (2016) 29–38

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Review Article

A practical implementation of Robust Evolving Cloud-based Controller with normalized data space for heat-exchanger plant

Goran Andonovski [a,*], Plamen Angelov [b], Sašo Blažič [a], Igor Škrjanc [a]

[a] Faculty of Electrical Engineering, University of Ljubljana, Slovenia
[b] School of Computing and Communications, Lancaster University, United Kingdom

ARTICLE INFO

Article history:
Received 7 February 2016
Received in revised form 6 May 2016
Accepted 25 May 2016
Available online 23 June 2016

Keywords:
Evolving system
Robust adaptive control
Fuzzy cloud-based system

ABSTRACT

The RECCo control algorithm, presented in this article, is based on the fuzzy rule-based (FRB) system named ANYA which has non-parametric antecedent part. It starts with zero fuzzy rules (*clouds*) in the rule base and evolves its structure while performing the control of the plant. For the consequent part of RECCo PID-type controller is used and the parameters are adapted in an online manner. The RECCo does not require any off-line training or any type of model of the controlled process (e.g. differential equations). Moreover, in this article we propose a normalization of the cloud (data) space and an improved adaptation law of the controller. Due to the normalization some of the evolving parameters can be fixed while the new adaptation law improves the performance of the controller in the starting phase of the process control. To assess the performance of the RECCo algorithm, firstly a comparison study with classical PID controller was performed on a model of a plate heat-exchanger (PHE). Tuning the PID parameters was done using three different techniques (Ziegler–Nichols, Cohen–Coon and pole placement). Furthermore, a practical implementation of the RECCo controller for a real PHE plant is presented. The PHE system has nonlinear static characteristic and a time delay. Additionally, the real sensor's and actuator's limitations represent a serious problem from the control point of view. Besides this, the RECCo control algorithm autonomously learns and evolves the structure and adapts its parameters in an online unsupervised manner.

Contents

* Corresponding author.
E-mail addresses: goran.andonovski@fe.uni-lj.si (G. Andonovski), p.angelov@lancaster.ac.uk (P. Angelov), saso.blazic@fe.uni-lj.si (S. Blažič), igor.skrjanc@fe.uni-lj.si (I. Škrjanc).

http://dx.doi.org/10.1016/j.asoc.2016.05.036

1. Introduction

Nowadays, control of nonlinear and complex processes is still an active research topic. Besides changing circumstances, process dynamics and complexity of the processes the industrial markets require high and satisfactory performance of the controller. A local linear approximation of the process combined with the classical PID controller provides good results but only in the neighborhood of the linearized operating point while this approach is not suitable for the whole operating range of the nonlinear process.

To solve the problem of nonlinearity the authors in [1] presented a self-tuning method for a class of nonlinear PID control systems based on Lyapunov approach. Another scheme in [2] is presented where the just-in-time learning technique is employed to predict the process dynamics and furthermore, the Lyapunov method for adapting the PID parameters is used. There are many other techniques and methods, for example, in [3] an online adaptation of PID controller using neural networks is proposed and in [4] the genetic algorithm for finding the optimal PID parameters is applied. Also the particle swarm optimization for tuning the parameters of PID controller in [5] is used. Another type of PID controllers are Fractional Order PID (FO PID) controllers that perform better than a classical PID-s [6] but require setting of two additional parameters. Similar to classical ones, tuning of this parameters can be solved by solving an optimization problem [7–9].

Fuzzy systems represent control scheme which is developed to deal with the nonlinear processes and due to their powerful adaptability and nonlinear modeling capability they are widely used in many applications [10–17]. The author of fuzzy sets/systems is Prof. Lotfi A. Zadeh who firstly introduced the theory in [18]. After Prof. Zadeh has introduced the theory of fuzzy sets, Mamdani in [19] published the first fuzzy model based control application on dynamic plant (a model of steam engine). Another fuzzy control system is Takagi–Sugeno (TS) fuzzy approach proposed in [20] that has attracted lots of attention after the publication. The wide popularity and usage of the fuzzy control systems is presented in [21] where a lot of fuzzy control schemes are discussed. Similar to TS fuzzy models a new tensor product (TP) models were developed. One of the advantages of the TP models is that the linear matrix inequality (LMI)-based control design can be applied directly to TP models. Recently, several process control solution using TP models were proposed for different applications [22–25].

Mamdani and TS fuzzy systems are made up of IF-THEN fuzzy rules representing the local linear input/output relations of a nonlinear system. The first part (IF) of the conditional is termed the antecedent, and the second part (THEN) is the consequent. Although, both TS and Mamdani are fuzzy systems, they have some differences, especially in the way how the conditional part is defined. Both fuzzy systems – TS and Mamdani – have a fuzzy antecedent part, while they differ in the consequent part which has the form of a functional (often linear) in the case of TS systems and a form of fuzzy logic in the case of Mamdani systems (see Table 1).

Besides the classical fuzzy rule-based (FRB) systems, TS and Mamdani, Angelov and Yager proposed a new simplified type of FRB system named ANYA in [26]. Moreover, they presented a new concept how the antecedent part is defined. As we have already mentioned above in both classical FRB systems the antecedent part is fuzzy and uses predefined and fixed membership functions of triangular, trapezoidal, Gaussian type, etc. ANYA FRB system extracts the information from the **real data** and form the data *clouds* to define the membership function. The clouds are sets of data that have common properties (they are close to each other in the data space). All data have different degree of memberships to the existing clouds determined by the local density of the data sample to **all** data from the particular cloud.

In [26] the authors distinguished between the clouds and the clusters and they pointed out the main differences between them. In general, the clouds do not require *a priori* information about the total number of membership functions or even an assumption about its form (do not have boundaries). Moreover, data clouds represent **all** previous data samples that are associated with the cloud.

Inspired and motivated by the simplicity of the ANYA FRB system several approaches on process control were developed and tested on different simulation models [27,28] and on a real plant [29]. Firstly, in [27] a new fuzzy controller RECCo (Robust Evolving Cloud-based Controller) was introduced. The main advantage of the RECCo controller is that it does not require any information and knowledge about the controlled process (e.g. in a form of differential equations). Furthermore, it is **initialized** from the first data sample and learns autonomously while performing the control of the plant. Also the structure of the RECCo is not predefined but **evolves** in an online manner during the process control (adding new clouds – fuzzy rules). In [27,29] a new cloud is added according to the global density of the data while in [28,30] a simpler way using local density threshold is proposed. Finally, controller's parameters in the consequent part are also tuned and **adapted** autonomously using stable gradient-based learning method.

In this paper we propose an improvement of the RECCo controller presented in [28]. Our idea is by using the basic knowledge from the controlled process (input and output range, time constant and sampling time) to set/fix the initial parameters required by the algorithm. A new normalized data space is proposed and due to this the evolving parameter γ_{max} can be fixed (γ_{max} defines 'when' a new cloud is added and will be introduced later in more detail). Also the adaptation gain vector $\boldsymbol{\alpha}$ could be calculated using the range of the control variable and the default value. Thus the controller tuning is simplified which makes the approach more appealing for the use in practical applications. Different initial real life scenarios were analyzed and new improved adaptation law with absolute values in the starting phase is proposed to improve the performance of the controller [31]. This improvement speed up convergence and reduce large transients when the initial are far away from the unknown parameters.

In order to show the effectiveness of the proposed controller, we provide several experiments on a real plate heat-exchanger (PHE) plant and on a PHE model. Firstly, we compared the performance of the proposed algorithm RECCo with the classical PID controller on PHE model. The parameters of the PID were tuned using Ziegler–Nichols [32], Cohen–Coon [33] and by pole placement method [34]. Nowadays, the PHE is widely used in many different industries and it is suitable to apply for heating, cooling systems, heat-ventilation-air-condition (HVAC) system, in chemistry, pharmacy, food and beverages industry etc. The basic concept of the PHE is transferring the heat between two liquids (separate circuits) flowing on either side of thin metal plates. The dynamical characteristic of the PHE contains strong nonlinear behavior in gain and time constant and has time delay.