Engineering Applications of Artificial Intelligence 61 (2017) 8–20

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

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

Parallel realization for self-tuning interval type-2 fuzzy controller

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ARTICLE INFO

Keywords:
Interval type-2 fuzzy logic systems
Interval type-2 fuzzy PD controller
Interval type-2 fuzzy PI controller
Self-tuning controller

ABSTRACT

In this study, we propose the self-tuning interval type-2 fuzzy proportional derivative plus proportional integral (STIT2FPD+PI) controller, which consists of two fuzzy processors. The first is the IT2FPD+PI controller, which is a parallel combination of the IT2FPD controller and the IT2FPI controller and it is used as the main controller. The second is the tuning mechanism, which is a type-1 fuzzy logic system (T1FLS) that used as parameters tuning. The tuning mechanism generates the updating factors that update the output scaling factors (SFs), the output membership functions (MFs) and the degree of uncertainty for the input MFs. The proposed STIT2FPD+PI controller is implemented practically based on a microcontroller for controlling the overhead crane system. The test is established using the hardware-in-the-loop (HIL) simulation. The practical results show that the proposed STIT2FPD+PI controller improves significantly the performance over a wide range of system uncertainties.

1. Introduction

A type-2 fuzzy set (T2FS) is characterized by a fuzzy MF, unlike a T1FS where the membership degree is a crisp number (Castillo and Melin, 2008). Thus, a T2FS is able to model the uncertainties directly because it provides additional degrees of freedom (Mendel et al., 2006). The antecedent or consequent sets of the IF-THEN rules for a type-2 fuzzy logic system (T2FLS) are type-2. T2FLSs have been used in many control system applications (Hagras (2004); Hagras et al. (2007); Liu et al. (2007); Sepúlveda et al. (2007); Dereli et al. (2011); Li and Sun (2012); Castillo et al., (2012, 2016b); Cervantes and Castillo (2015); Sanchez et al. (2015); Tai et al. (2016)). The IT2FLS is a special case of the T2FLS, which have been designed for various applications (El-Bardini et al. (2010); Castillo et al. (2011, 2016a); El-Bardini and El-Nagar (2011); Kumbasar et al. (2011); Cazarez-Castro et al. (2012); Sepúlveda et al. (2007, 2012); Cortes-Rios et al. (2014); El-Nagar et al. (2014); El-Nagar and El-Bardini (2014a), (2014b); Liu et al. (2014); Lu (2015); El-Nagar and El-Bardini, 2016).

The structure of the T2FLS consists of four parts that are a fuzzification process, a rule base, an inference engine, and an output processor. The output sets for the IT2FLS are interval type-2, which feed to an extended defuzzification operation to give a T1FS at the output. Since this is called a type-reduction (TR) and calls the type-1 set so obtained a type-reduced set (Karnik and Mendel, 1998). Karnik-Mendel (KM) algorithms are used to perform the TR that are computationally intensive (Karnik et al., 1999). There are several methods of TR, which are usually faster than the KM algorithms (Wu, 2013; El-Bardini and El-Nagar, 2014a, 2014b; El-Nagar and El-Bardini, 2014c).

As reported in El-Nagar and El-Bardini (2014d), it is convenient to combine the IT2FPD controller and the IT2FPI controller in a parallel structure to form an IT2FPD+PI controller. Our work in El-Nagar and El-Bardini (2014e) drives the analytical structures and stability analysis for the IT2FPD+PI controller. We obtained that the equivalent gains for the IT2FPD+PI controller are dependent on the inputs and outputs SFs, the output MFs and the degree of uncertainty for the input MFs. The tuning of these parameters has given strong influence on the performance. The fuzzy logic control (FLC) is called self-tuning or adaptive if any one of its parameters (SFs, MFs and rules) changes when the controller is being used, otherwise it's a non-adaptive FLC (Mudi and Pal, 1999). The main objective of this paper is tuning the parameters of the IT2FPD+PI controller; the output SFs, the outputs MFs and the degree of uncertainty in the inputs MFs. We call the tunable controller the STIT2FPD+PI controller. The structure of the proposed STIT2FPD+PI controller is consists of two fuzzy processors. The first is an IT2FPD+PI controller, which acts as the main fuzzy controller, and the second is the tuning mechanism, which is T1FLS that used as parameters tuning. The proposed STIT2FPD+PI controller using our simplified TR method (El-Bardini and El-Nagar, 2014a, 2014b; El-Nagar and El-Bardini, 2014c; El-Nagar, 2016) is implemented practically based on the P18F4685 microcontroller for controlling the overhead crane system. The HIL simulation is used for testing the performance of the proposed STIT2FPD+PI controller. The practical results show that the proposed STIT2FPD+PI controller improves

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http://dx.doi.org/10.1016/j.engappai.2017.02.011
Received 7 September 2016; Received in revised form 9 January 2017; Accepted 16 February 2017
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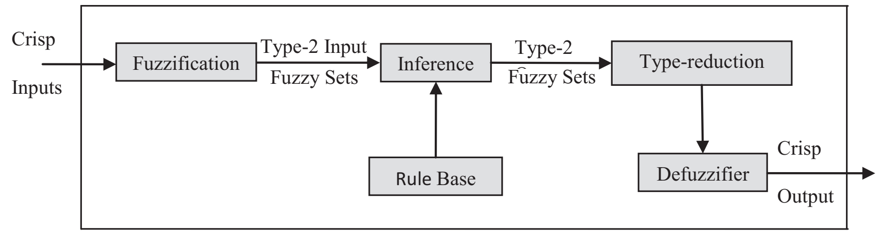

Fig. 1. Block diagram of the interval type-2 fuzzy system.

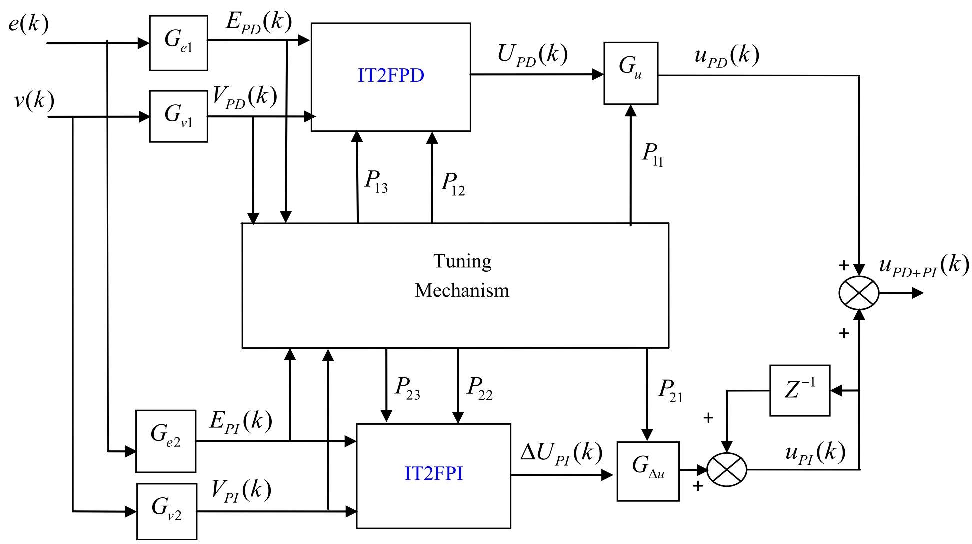

Fig. 2. Structure of the proposed STIT2FPD+PI controller.

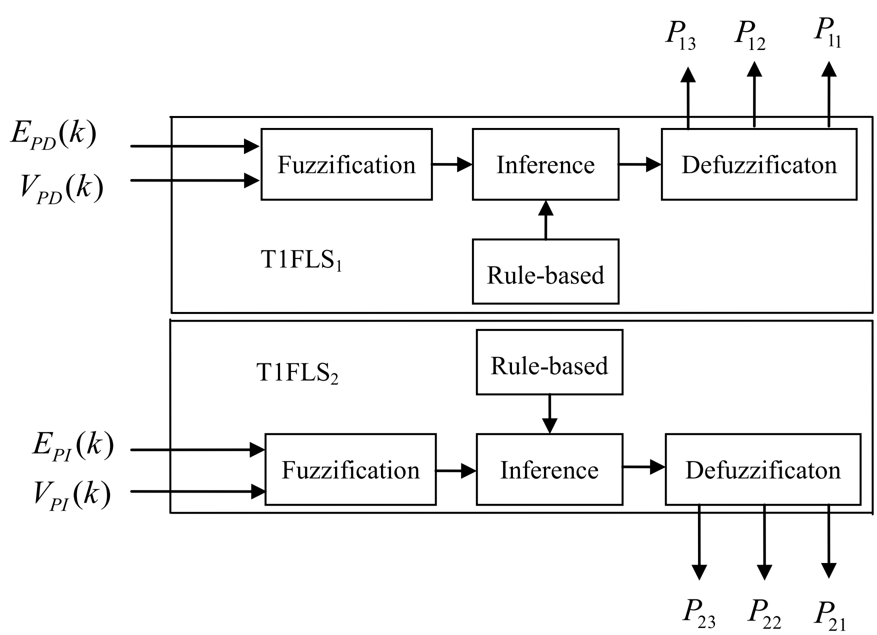

Fig. 3. The tuning mechanism.

significantly the performance over a wide range of system uncertainties and external disturbances compared with other controllers.

The main contributions of this study are summarized as: 1) Designing an adaptive type-2 fuzzy controller, which named STIT2F-PD+PI controller using the simplified type-reduction method. 2) Parallel realization for the proposed controller based on a microcontroller. 3) Applying the proposed controller for controlling the overhead crane system to overcome the uncertainties due to parameters uncertainties, measurement error uncertainties and external disturbances.

The rest of the paper is organized as follows. In Section 2, the background about interval type-2 fuzzy system is presented. The self-tuning interval type-2 fuzzy PD+PI controller is described in Section 3. Section 4, presents the mathematical model of the overhead crane system. Section 5, presents the parallel realization of the proposed controller and experimental results followed by the conclusions.