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Optimal Design of Fuzzy Fractional Order $PI^{\lambda}D^{\mu}$ Controller for Redundant Robot

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Abstract

The aim of this paper is to compare the performances of new fuzzy fractional order (FO) PID (fuzzy $PI^{\lambda}D^{\mu}$) controller with integer order fuzzy PID and PID controllers for controlling redundant robotic system for trajectory tracking problems. A five-degree of freedom (5-DOF) redundant manipulator is an MIMO, and extremely non-linear system. The performances of the controlled system are poorly affected by the presence model uncertainties and external disturbances. Thus, controller design for redundant robot system is difficult job for controller designer. The tuning of each controller's parameters is completed with artificial bee colony (ABC) optimization techniques. For investigating the effectiveness, the robustness testing is also investigated for model uncertainties and disturbance rejection. After many numerical simulations and comparison with conventional controller i.e. fuzzy PID and PID controllers, it is found that fuzzy $PI^{\lambda}D^{\mu}$ controller can not only promise best trajectory tracking but also meliorate the plant robustness for model uncertainties and disturbance rejection.

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Keywords: Fuzzy logic controller; Fractional order $PI^{\lambda}D^{\mu}$ controller; Trajectory tracking; Five-DOF redundant manipulator; Robustness testing

1. Introduction

From the past many years, the robot systems are primarily used in the industries because they reduce the production cost, enhance precision, quality, and productivity. The designing of the controllers has various practical challenges due to the complication involved in the dynamic of robots. The conventional robot controllers require

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highly precise dynamic modeling. Therefore, these methods are not appropriate for controlling the structured and unstructured uncertainties. Thus, the artificial intelligence provides an efficient way to combat with this.

In the past, a number of applications on fractional calculus are amplified in controller design because of additional flexibility [1]. Various authors have evinced the FOPID controllers and their extension to FLCs for different applications. Recently, nonlinear FOPID controller is implemented for controlling of 5-DOF robots [2]. Gaidhane et al. [3] presented 2DOF-FOPID controller for magnetic levitation system. In continuation, fractional order fuzzy pre-compensator control approach is implemented for controlling of 2-DOF robots [4]. Most recently, Kumar and Kumar [5] proposed interval type-2 fractional order fuzzy controller for controlling of linear and non-linear plants. Further, family of hybrid IT2FO-FPID controllers are presented for fractional order plants [6]. Recently FO controllers are widely used by many authors, this is mainly because these controllers have an extra flexibilities that is making the controller more robust. It is also claimed from above review that presented controllers have been producing better results than its counterparts.

From the literature survey, it can be concluded that FO controller is still in early stage and its implementation to redundant manipulator is a challenging task. The motivation for this research work is an exploration of fractional mathematics to the FLC, which introduces extra flexibilities for tuning of control loops. Due to this, the fuzzy $PI^{\lambda}D^{\mu}$ controller is less sensitive to change in the controlled plants and controller itself. The novel work proposed by Jesus and Barbosa [7] (here, the integral term is integer form only) is extended here for controlling the 5-DOF robot.

This study is prepared as follow: Section 2 presents the dynamic modeling of the redundant robot of SCARA type is presented. Further, the structural design of fuzzy $PD^{\mu} + I^{\lambda}$ is presented in Section 3. The ABC is expressed in Section 4. Simulation result analyses are given in Section 5. At last, in Section 6, the conclusion is given.

2. Mathematical modeling of redundant robotic system

Redundant robot manipulators are designed with extra-DOF than necessary to do a specified task. This redundancy is a significant feature in a redundant robot to perform obstacle avoidance and collision-free task [8,9]. Fig. 1 shows a schematic diagram of 5-DOF robotic that contains rotational and prismatic redundancy.

In Fig.1, where q_1, q_2, q_3, q_4, q_5 are generalized coordinates (displacement d or angle θ), l_1, l_2, l_3, l_4, l_5 are the length of links and l_{c2}, l_{c3}, and l_{c4} are the lengths from origin to the centroid of the link.

The mathematical modelling of 5-DOF redundant manipulator has been described by Eq. (1) [9].

$$M(q)\ddot{q}+C(q,\ddot{q})+G(q)+F(\dot{q})=\tau \quad (1)$$

In Appendix A, details of mathematical modeling (Eq. (1)) are presented.

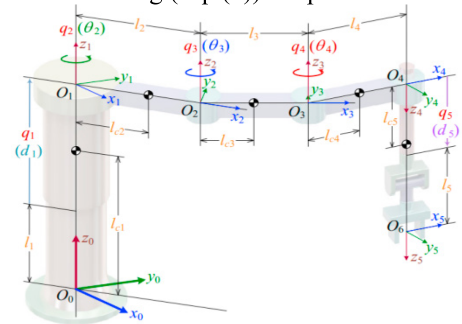

Fig. 1 Schematic diagram of 5-DOF redundant robot manipulator [8].

3. Design and implementation of fuzzy $PI^{\lambda}D^{\mu}$ controller

To implement the fuzzy PID controllers, PID controller is used with three input expressions: error, the rate of change of error and integration of error. These premise inputs can produce large rules such as rules with three premise inputs and seven MFs, it may become 7 x 7 x 7 i.e. 343 rules, which is quite large and hard to handle such a big rules. Hence, it is necessary to split the integral control term [10]. Thus, fuzzyPD plus traditional I control action requires only 2-dimensional rule base (7^2=49). Further, for implementation of fuzzy $PI^{\lambda}D^{\mu}$ controller, fractional