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# Design of two-layered fractional order fuzzy logic controllers applied to robotic manipulator with variable payload

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ABSTRACT

The robotic manipulators are highly coupled and nonlinear systems wherein the time-varying parameters and uncertainties adversely affect the characteristics and response of these systems. Hence, these systems require an effective and robust controller to handle such complexities which is a difficult challenge for control engineers. This paper presents two-layered fractional order fuzzy logic controller (TL-FOFLC) scheme for a two-link planar rigid robotic manipulator with payload for trajectory tracking task. For the optimal design, the controller parameters of the proposed scheme are obtained with potential meta-heuristic technique named as cuckoo search algorithm (CSA). In order to ensure effectiveness, the performance of proposed TL-FOFLC is compared with that of its integer order design approach, i.e., two-layered FLC (TL-FLC), single-layered FLC (SL-FLC), and the conventional proportional-integral-derivative (PID) controllers. Further, the robustness testing is carried out for parameter variations and external disturbance rejection.



## 1. Introduction

Recently, the robotic manipulators have widely been used in the industrial, medical and space applications, especially, for the purpose of accurate positioning and path following. For the precise execution of the motion, it is essential to provide an effective control to the end-effector of a robotic manipulator. These systems are highly nonlinear, uncertain and interacting in nature. The operation of robotic manipulators is also affected by various parametric uncertainties and external disturbances. To deal with such uncertainties and complexities, there is a need of development of an effective and robust control scheme for these systems.

The introduction of fuzzy logic, in the world of control theory, has remarkably enhanced the applicability controllers to control the complex and nonlinear plants. The FLC offers new horizons in the field of control engineering due to its several advantages over classical approaches such as involvement of human expertise, model-free and flexible approach etc. Unlike the conventional PID controller, it can effectively deal with system uncertainties and nonlinearities [1–3]. Song et al. presented a hybrid scheme with combination of classical computed torque control technique and fuzzy logic for the two-link planar robotic manipulator wherein the fuzzy logic was used as the compensator and worked effectively for uncertainties [4]. Sooraksa and Chen investigated fuzzy logic with PID controller for trajectory tracking as well as vibration suppression for a flexible-link robotic system [5]. Meza et al. presented real-time investigation of fuzzy self-tuning PID controller for a direct drive vertical robotic manipulator. The semiglobal asymptotic stability of the proposed scheme was obtained using Lyapunov theory [6]. Sanchez et al. presented a generalized Type-2 fuzzy control scheme for a mobile robot. It was found that the proposed control scheme outperforms Type-1 and interval Type-2 FLC in the presence of external noises [7].

In the recent times, several control engineers have been working towards different design structures of FLCs, to develop more efficient control techniques. Kim et al. proposed TL-FLC scheme for the systems having deadzone nonlinearities. The two-layered control scheme, consists of a fuzzy pre-compensator and a traditional FLC, has superior performance as compared to the traditional fuzzy Proportional-Derivative (PD) controller in terms of transient and steady-state response [8]. Pratumsuwan and Thongchai experimentally investigated the effectiveness of TL-FLC scheme for a proportional hydraulic system having the deadzone nonlinearities [9]. From the literature, it seems that the TL-FLC scheme may also

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**Table 1**
Parameters for a two-link planar rigid robotic manipulator.

| Parameters | Link1 | Link2 |
|---|---|---|
| Mass | 0.392924 kg | 0.094403 kg |
| Acceleration due to gravity (g) | 9.81 m/s$^2$ | 9.81 m/s$^2$ |
| Length | 0.2032 m | 0.1524 m |
| Distance from the joint of link to its center of gravity | 0.104648 m | 0.081788 m |
| Lengthwise centroid inertia of link | 0.0011411 kg m$^2$ | 0.0020247 kg m$^2$ |
| Friction at joints | 0.141231 N-m/radian/s | 0.3530776 N-m/radian/s |

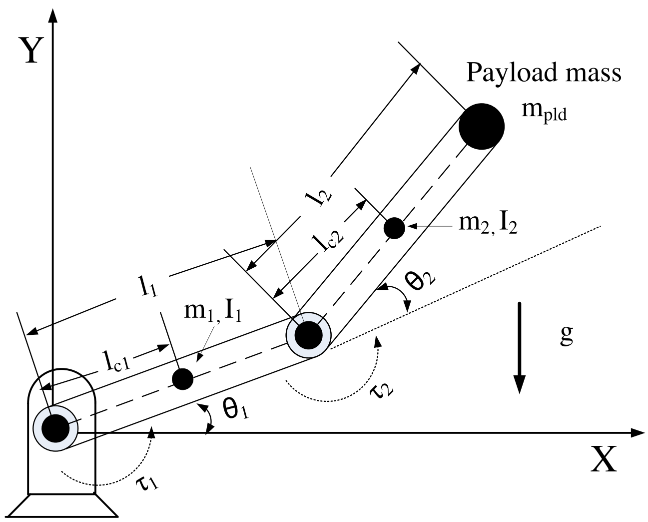


**Fig. 1.** Two-link planar rigid robotic manipulator with payload at tip.

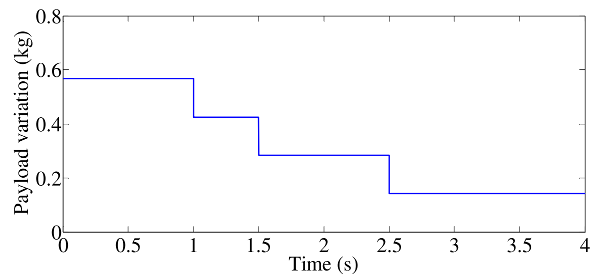


**Fig. 2.** Payload variations at the tip.

be applied to robotic manipulator systems having inherent nonlinearities and uncertainties.

For the last few years, there have been overwhelming participation of fractional calculus in the field of control theory applications, and are applied to different plants such as aerofin control system [10], automatic voltage regulator [11], power system [12] and some fractional order plant [13] etc., in the form of fractional order PID (FOPID) controllers. The significant advantage of fractional order design is that the orders of both the conventional integrator and differentiator terms are indicated by non-integer values rather than integer ones. Efe presented the use of fractional calculus in the design of various control schemes such as FOPID, sliding mode control, backstepping control and adaptive control etc. [14]. Sharma et al. presented a two-degree of freedom FOPID controller for the robotic manipulator applications [15].

Recently, various authors have investigated fuzzy logic with fractional order mathematics for the design of controllers. Das et al. presented fractional order fuzzy controller for the delayed nonlinear systems and the open-loop unstable systems with time delay, and found that this controller is better than the other three controllers namely fuzzy PID, FOPID and traditional PID controllers [16]. A comparative study for the different design structures of the fractional order fuzzy PID (FOFPID) controller for the oscillatory fractional order systems with dead time. The performance of different controllers were obtained for the set-point tracking, control effort and disturbance rejection [17]. Sharma et al. presented the FOFPID controller for the two-link planar robotic manipulator for the trajectory tracking task, and found it to be superior to other conventional controllers for the trajectory tracking, disturbance rejection, parameter variations and noise suppression [18]. In [16–18], it was concluded that the performance of FOFPID scheme is superior to conventional FLC approaches. From the literature, it seems that the TL-FOFLC scheme have not been developed for control applications yet. Therefore, this scheme may be explored for the robotic manipulator applications for enhancing the performance and robustness of the controller.

For providing an effective control, there is a need of optimal design parameters for the designated controller for any plant. The development of heuristic and nature-inspired optimization methods is a paradigm in the field of artificial intelligence. Several heuristic and evolutionary optimization techniques namely genetic algorithm (GA) [19], particle swam optimization (PSO) [20], differential evolution [21], simulated annealing [22] and bat algorithm [23] etc. have extensively been used in the literature for obtaining the parameters for different plants. Various authors have investigated the optimization of FLC schemes with different optimization techniques. Precup et al. presented a fairly good survey on the optimization of the different parameters of the FLC schemes [24]. Caraveo et al. presented a bee colony optimization method for obtaining the optimal parameters of FLC [25]. In [26], Bingul and Karahan proposed trajectory control of robotic manipulator using FLC and the tuning of FLC was done with PSO. In [27], Mahalakshmi and Sumathi presented fuzzy differential evolution algorithm for the 7-DOF serial link robotic system for trajectory optimization task. Gaxiola et al. presented the optimization of Type-2 fuzzy inference system using GA and PSO. The optimized Type-2 fuzzy weights of the back propagation neural networks [28]. Guerrero et al. presented a new CSA wherein the fuzzy system is used to adapt its parameters. The proposed optimization method was found to be more effective than conventional CSA for a set of mathematical functions [29]. Sanchez et al. presented the information granules formation using the concept of uncertainty based information with the interval Type-2 fuzzy sets. The Takagi-Sugeno-Kang consequents are optimized with CSA [30].

Despite its nascent stage, CSA has been investigated for different applications. Civicioglu and Besdek presented a detailed comparative study among various optimization techniques namely Cuckoo search, PSO, Differential evolution and artificial bee colony, for 50 different benchmark functions [31]. Manikandan et al. presented CSA for the clustering of data [32]. In [33], Patwardhan investigated a CSA based infinite impulse systems identification scheme. Yildiz presented the application of CSA for obtaining the cutting parameters for milling operation and the results obtained were claimed to be better than many optimization techniques such as GA, hybrid PSO, hybrid immune algorithm, feasible direction method, hand-