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Dynamic Performance Enhancement of Fractional-Order PID Controller using a High-Level Ensemble Swarm Intelligence Method

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Abstract—This paper deals with the optimal design of fractional-order proportional-integral-derivative (FOPID) controller using a high-level ensemble method. An ensemble particle swarm optimization (EPSO) algorithm is employed to determine the five design parameters of the FOPID controller based on a time-domain approach. Several design examples, including time-delay system, DC motor plant transfer function, etc., are considered to demonstrate the suitability of the proposed strategy. Results reveal that the closed loop control system employing the EPSO-based controller can achieve an optimal and improved dynamic performance as compared to the reported literature.

Index Terms—ensemble particle swarm optimization, fractional calculus, fractional order PID controller, optimization

I. INTRODUCTION

In the end of the seventeenth century, Gottfried Leibnitz introduced a bright thought about fractional calculus (FC) [1]. Presently, FC has been widely used in describing the features of real-life systems in science and engineering. Due to better theoretical understanding, since the past two decades, FC has been extensively used in well-known classical fields of science and engineering such as electro-chemistry, signal processing, thermal engineering, power system, visco-elasticity, fluid mechanics, optics, electromagnetics, etc. [2]. FC has also been applied in less well known fields which include filter design, capacitor theory, fractional multipoles, electrode-electrolyte interface models, bio-impedance modeling, modeling of neurons, etc. [3], [4], [5].

Modern design tools encourage researchers to use FC in solving control engineering problems [6]. As a result, numerous comprehensive studies have been proposed to establish connections between control problem with fractional-order (FO) integral and derivative [7], [8]. Among the several

definitions of FO derivative prevalent in the literature, the definition as per Caputo is given in (1) [1].

$$D_{t_0}^\alpha f(t) = \frac{1}{\Gamma(m-\alpha)} \int_{t_0}^t (t-\tau)^{m-\alpha-1} f^{(m)}(\tau) d\tau \quad (1)$$

where $f(t)$ is a causal function; m is an integer; and $\alpha \in (m-1, m]$. If the initial conditions are set to zero, the Laplace transform of (1) is given by $s^\alpha F(s)$.

One of the seminal works that dealt with the applicability of fractional-order proportional-integral-derivative (FOPID) controller is cited in [9]. The continuous-time transfer function of an FOPID controller is given by (2).

$$G_C(s) = k_p + \frac{k_i}{s^\lambda} + k_d s^\mu \quad (2)$$

where the controller gains for proportional, integral, and derivative actions are denoted by k_p , k_i , and k_d , respectively, and $\lambda, \mu \in [0, 2]$.

In contrast to the classical PID controller where the values of λ and μ are strictly equal to one, an FOPID controller can take non-integer values for these two new design parameters. Hence, instead of only three tuning parameters available in classical PID controller, a $PI^\lambda D^\mu$ controller possesses five ‘tuning knobs’. This lends additional flexibility to the FOPID controller in meeting stringent control specifications. Tuning and implementation techniques of the FO controllers is a dynamic area of research [10], [11]. The block diagram of a unity feedback system involving the FOPID controller and plant transfer function $G_P(s)$ is shown in Fig. 1. The closed loop transfer function of this system is given by (3).

$$\frac{Y(s)}{U(s)} = \frac{G_C(s)G_P(s)}{1 + G_C(s)G_P(s)} \quad (3)$$