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PSO-OPTIMIZED FRACTIONAL ORDER ITERATIVE LEARNING CONTROLLER FOR 3DOF UNCERTAIN EXOSKELETON SYSTEM

Živković LJ. Nikola[1], Lazarević P. Mihailo[2]

[1] Lola institute Ltd.,
Kneza Višeslava 70a, 11030 Belgrade, Serbia
e-mail: nikola.zivkovic@li.rs
[2] Faculty of Mechanical Engineering,
The University of Belgrade, Kraljice Marije 16, 11120 Belgrade 35
e-mail: mlazarevic@mas.bg.ac.rs

Abstract:

This paper proposes a Fractional-order Iterative Learning Control (FOILC) algorithm combined with feedback linearization for the upper limbs rehabilitation exoskeleton. The control system is divided into an inner and outer loop, where the feedback linearization controller closes the inner loop linearizing the nominal part of the robot dynamics. The outer loop consists of feedforward action and classical feedback controller with Proportional and Derivative action (PD). Feedforward action is proposed as the FOILC of the PD^{α}-type, where α is the fractional derivative order. Since feedback linearization control action can cancel only a nominal part of the model dynamics, uncertainty is introduced as an additive uncertainty. The uncertainty is defined as a change in the mass parameter of each exoskeleton link [1]. The control object is a three-DoF open-chain exoskeleton model. The mathematical model of the exoskeleton is modeled in Simulink using Robotics Toolbox. The feedback linearization controller is the model-based controller, which accounts for the known part of the dynamics leaving the uncertain part uncontrolled. A classical PD feedback controller is introduced alongside FOILC in feedforward to stabilize and improve the tracking performance of the linearized system with uncertainties. The main advantage of FOILC is robustness to uncertainty and disturbances that are non-varying along the iteration axis. In this study, we chose the FOILC controller, a variation of ILC, to improve trajectory tracking with present uncertainties in the exoskeleton system model. The FOILC controller consists of the previous control signal, proportional and fractional order derivative terms. The learning gains and fractional order of the FOILC are optimized using the Particle Swarm Optimization (PSO) method. PSO is a population-based stochastic optimization method inspired by the social behavior of birds flocking or fish schooling. The main idea of PSO is to search for an optimal solution by simulating the social behavior of particles moving in a multi-dimensional search space. PSO is particularly well-suited for this problem since we have nine parameters in total for tuning. This research aims to investigate the behavior of the error convergence over iterations with optimized learning gains and fractional order of the FOILC controller for various percentages of the mass parameter change. The numerical simulation is conducted in Matlab and Simulink with the time step Ts = 0.005s. The desired trajectory is defined in the joint space as a fifth-order polynomial. The infinite norm of the error vector (max norm) for each iteration is used as a measure of the performance of the proposed control system. Figure 1. shows the error norm comparison between different percentages of mass

uncertainty, and Figure 2. shows the difference between PSO-optimized FOILC and non-optimized integer order ILC for mass uncertainty equal to 30 percent of the original mass of the links.

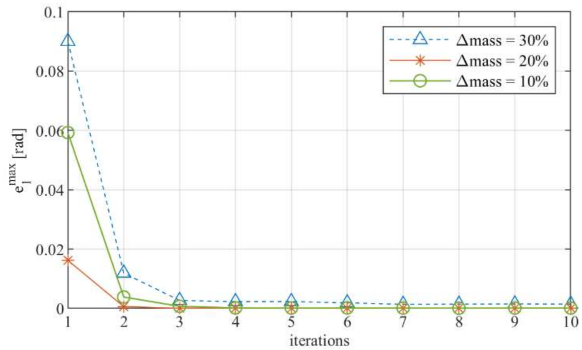

Fig. 1. Error norm of the joint 1 for different mass percentages

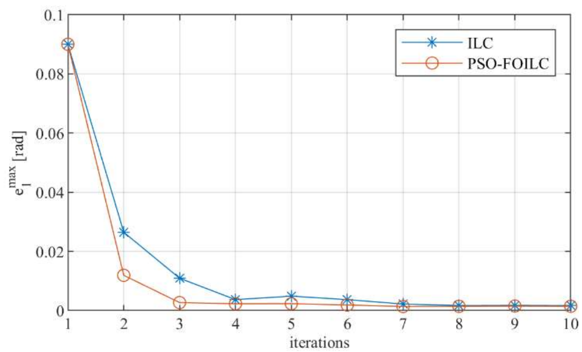

Fig. 2. Error norm of the joint 1 for optimized FOILC and non-optimized ILC

From previous diagrams it is clear that PSO optimized FOILC converges faster than its non-optimized integer order counterpart and that PSO optimized FOILC displays satisfactory robustness to different mass uncertainties.

Key words: Iterative learning control, fractional derivative, feedback linearization, particle swarm optimization, uncertainty

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