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Iterative learning control scheme for manipulators including actuator dynamics

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Abstract

This paper presents the iterative learning control for the industrial robot manipulators including actuator dynamics. Motivated by human learning, the basic idea of iterative learning control is to use information from previous execution of a trial in order to improve performance from trial to trial. This is an advantage, when accurate model of the system is not available as friction and actuator dynamics, though present in the system, are not modeled to reduce the computational complexity. In this paper different aspects of ILC including the design schemes and control algorithms are covered. The learning control scheme comprises two types of control laws: a linear feedback law and a feed-forward control law. In the feedback loop, the fixed gain PD controller provides stability of the system and keeps its state errors within uniform bounds. In the feed-forward path, a learning control rule/strategy is exploited to track the entire span of a reference input over a sequence of iterations. Algorithms are verified through detailed simulation results on a two DOF robot manipulator.

Keywords: Iterative learning control; Actuator dynamics; Robot control

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1. Introduction

Iterative learning control is a technique for improving the transient response and tracking performance of processes, machines, equipments or systems that execute the same trajectory, motion or operation in a repetitive manner. There are numerous problems that can be viewed from the framework of repetitive operations such as Industrial robotic operations, Chemical processes, etc. In these situations ILC can be used to improve the system response. The approach is motivated by the observation that if the system controller is fixed and if the system's operating conditions are the same each time it executes, then any errors in the output response will be repeated during each operation. These errors can be recorded during system operation and can be used to compute modifications to the input signal that will be applied to the system during the next operation, or trial. The ILC based algorithms take care of the non-linear effects such as friction, actuator dynamics effects (electrical effects), which occur in very high speed operations and highly varying load conditions. In ILC, refinements are made to the input signal after each trial until the desired performance level is reached.

ILC has been an active research area for more than a decade that can accommodate varying environments and modeling errors [1–5,8,9]. The term ILC was introduced first by Arimoto et al. [2], where it is mentioned as "*a betterment process*". Higher order ILC for a class of non-linear dynamic systems uses more historical data to get the better output tracking performance as an extension of first order methods [3]. New ILC control schemes are given by [5,7] in which, the conventional feedback control scheme in combination with the ILC was proposed. The stability analysis of learning control scheme with disturbances and uncertain initial conditions were discussed in [6].

The control objective here is to make the robot manipulator track a given trajectory. However, this objective is in general very difficult to achieve by conventional control methods due to the inherent non-linearity and the unmodeled dynamics. The situation becomes even worse when the unknown system parameters have time-varying effects such as payload changes, mechanical wear, aging, etc. This type of system changes, as well as the external disturbances is extremely difficult to manage. As a way to overcome this difficulty the iterative control techniques that searches for a desired input torque/voltage through a sequence of repetitive operations. That is, by training the system through the repetitive operations, we are aiming at reducing tracking error as the iteration increases. In most of the literature, ILC is adopted for robot manipulator without considering actuator dynamics. However the actuator dynamics constitute an important part of the complete robot system [12], especially in the cases of high-velocity movements and highly varying loads. The inclusion of actuators into the manipulator dynamics will lead to further complication of the controller structure and its stability analysis [13].

The objective of this paper is to obtain insight and experience with ILC and its application to the industrial robotic manipulator with the consideration of its actuator dynamic effects. For this purpose, the mathematical background of ILC techniques is discussed in Section 2. In Section 3, the detailed state-space description of the robot manipulator dynamics including the actuator dynamics and friction are derived for the purpose of simulation studies. Two different types of ILC algorithms based on gradient descent, high-gain feedback methods for non-linear systems are discussed in Section 4. The efficacy of the ILC algorithms has been verified by simulation studies on a two link robot manipulator discussed in Section 5.