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ONLINE FEEDBACK ERROR LEARNING CONTROL FOR AN INVERTED PENDULUM

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Abstract. *This paper presents an application of the feedback error learning technique for online control of an inverted pendulum which has uncertain friction nonlinearity. In order to build up online adaptive learning control, i) the preliminary offline training and the scaling factor for the neural network to escape from the local minimum, and ii) two-stage learning scheme are introduced. After some learning cycles, the vibrations of the inverted pendulum are completely ceased that the feedback error learning scheme acts as an adaptive controller to minimize the control error. This means that the neural network acquires the inverse dynamic model of the plant through learning, and then compensates the nonlinearity of the plant. The phase relationships of the control outputs between the conventional feedback controller and the adaptive neural network controller are clarified. It is also shown that this control system works well for a step reference signal after learning.*

Keywords: Online feedback error learning, Neural network, Scaling factor, Inverted pendulum, Nonlinear system

1. **Introduction.** Artificial neural network models are widely used in many industrial fields such as pattern recognition, motor control and process control systems. Recently, Kawato and his group proposed a novel architecture of adaptive control system called feedback error learning (FEL) architecture which includes both a conventional feedback controller (CFC) and a neural controller that acts as an adaptive nonlinear feedback controller (NNFC) with synaptic weights suitably changing for the error signal of the output of the CFC [1, 2]. This adaptive nonlinear feedback control design procedure is developed for highly uncertain nonlinear systems that do not rely on state estimation. They applied this architecture to control of the inverted pendulum system [2]. Another novel framework of an adaptive nonlinear feedback controller based on a modular network SOM (self-organizing map) has been studied by Minatohara et al. [3]. However, only the simulation results have been reported hitherto for the inverted pendulum with nonlinear characteristics.

In this paper, we present the experimental results of the FEL technique for online control of an inverted pendulum system which has unknown friction nonlinearity. In order to build up online adaptive learning control, i) the preliminary offline training and the scaling factor for the neural network to escape from the local minimum, and ii) two-stage learning scheme are introduced. It is noted that, despite the results of the theoretical analysis [2, 3], the difference of the control outputs between the CFC and the NNFC must be applied to the controlled object called a "plant," for maintaining online FEL control. Furthermore, in the first stage the learning and momentum rate must be chosen