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Convergence and Energy Analysis for Iterative Adaptive On-Off Control of Piezoelectric Microactuators

Bongsu Hahn[1*] and Kenn Oldham[2]

[1]*Department of Applied Robotics, Kyungil University, Kyungsan 712-900, Korea*
[2]*Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI 48109, USA*

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Actuators in many micro-electromechanical system (MEMS) applications act as small capacitive loads and are desired to operate at very low power levels. When such microactuators are incorporated into feedback control systems under conventional approaches, driving and sensing circuitry may easily consume more energy than actuators.

One low-power approach to controlling microactuator motion is to perform iterative adaptive on-off control with limited numbers of sensor measurements when those motions can be expected to repeat many times, as for autonomous walking micro-robotics. The authors have described two iterative adaptive on-off controllers for thin-film piezoelectric micro-robotic leg joints, one based on stochastic gradient approximation and the other on deterministic heuristic switching rules. In both cases, eventual convergence of switching times to at least locally optimal values was guaranteed for some limited range of initial switching time selections and adaptation gains. No explicit model of the system is required for adaptation, though a nominal model is useful to ensure that adaptation gains are stable.

However, the rate at which the switching time selections converge to optimal values could not be predicted. Thus the controllers can limit the energy expended during each iteration (to about 10-30% of an analog controller with comparable response) but not make any predictions of total energy required to identify the optimal switching times. The aim of this research, then, is to estimate the rate of convergence of these on-off iterative adaptive controllers to optimal switching instances, then to show how this knowledge can be used to improve overall power or energy consumption by choice of sampling rates and/or number of switched inputs permitted.

The approach makes use of the binary nature of on-off inputs (0 or 1) and knowledge about adaptation behavior in the known regions of convergence. Analysis will be applied to two on-off adaptive controllers (the heuristic adaptive approach and stochastic gradient approximation approach). The resulting method for predicting output error as a function of iteration number is found to have reasonable agreement with simulated and experimental test cases.

Keywords: Microsystems; Switching Control; Iterative Control