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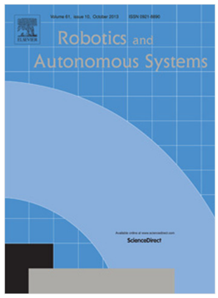

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Adaptive Natural Oscillator to Exploit Natural Dynamics for Energy Efficiency

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Abstract

We present a novel adaptive oscillator, called *Adaptive Natural Oscillator* (ANO), to exploit the natural dynamics of a given robotic system. This tool is built upon the Adaptive Frequency Oscillator (AFO), and it can be used as a pattern generator in robotic applications such as locomotion systems. In contrast to AFO, that adapts to the frequency of an external signal, ANO adapts the frequency of reference trajectory to the natural dynamics of the given system. In this work, we prove that, in linear systems, ANO converges to the system's natural frequency. Furthermore, we show that this tool exploits the natural dynamics for energy efficiency through minimization of actuator effort. This property makes ANO an appealing tool for energy consumption reduction in cyclic tasks; especially in legged systems. We also extend the proposed adaptation mechanism to high dimensional and general cases; such as n-DOF manipulators. In addition, by investigating a hopper leg in simulation, we show the efficacy of ANO in face of dynamical discontinuities; such as those inherent in legged locomotion. Furthermore, we apply ANO to a simulated compliant robotic manipulator performing a periodic task where the energy consumption is drastically reduced. Finally, the experimental results on a 1-DOF compliant joint show that our adaptive oscillator, despite all practical uncertainties and deviations from theoretical models, exploits the natural dynamics and reduces the energy consumption.

Keywords: Energy efficiency, Natural dynamics, Cyclic task, Adaptive oscillator, Pattern generator

1. INTRODUCTION

Energy efficiency along with stability and adaptability are the ultimate goals in most robotic applications, especially in cyclic tasks such as pick-and-place [1] and locomotion [2]. In a classical view towards motion generation and control, energy consumption is considered as a cost which can be optimized using numerous model-based methods such as optimal control [3]. However, such model-based approaches cannot be simply applied to nowadays robotic systems with compliant elements, nonlinearities, and hybrid dynamics. On the other hand, model-free optimization techniques, such as reinforcement learning [4] and adaptive control [5], can be easily applied for energy efficiency. Nevertheless, these methods suffer from slow and unwarranted convergence behavior. However, for energy-efficiency, focusing on *natural dynamics* can simplify and facilitate such methods. As presented in this work, we do not consider the energy efficiency as a blind optimization problem, but rather as the result of an adaptation between motion-generation and natural dynamics.

Broadly speaking, energy efficiency can be achieved using two different approaches: Natural Dynamics Modification (NDM see [6–9]) and Natural Dynamics Exploitation (NDE see [10–13]). While NDM methods aim the structure design of the robot, NDE approaches try to modify the motions in order to improve the energy efficiency. In other words, NDE methods include all types of motions generators which target energy consumption reduction —as an objective— in their

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