Learning impedance control based on stochastic optimisation principles

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Novel anthropomorphic robotic systems increasingly employ variable impedance actuation in order to achieve robustness to uncertainty, safety, superior agility and efficiency. Controlling and modulating impedance profiles such that it is optimally tuned to the controlled plant is crucial to realise these benefits.

This work focuses on the development of novel motor control strategies for variable impedance actuators. We propose a methodology to generate optimal control commands for variable impedance actuators under a prescribed trade-off of task accuracy and energy cost. The key question that we address here is how a controller can overcome the inherently "conflicting properties" between energy preservation and motor co-contraction in an optimal fashion. To achieve this, we employ a supervised learning paradigm to acquire *both* the plant dynamics and its stochastic properties (Figure 1). This enables us to prescribe the optimal impedance and command profile (i) tuned to the hard-to-model stochastic plant characteristics and (ii) adapt to systematic changes.

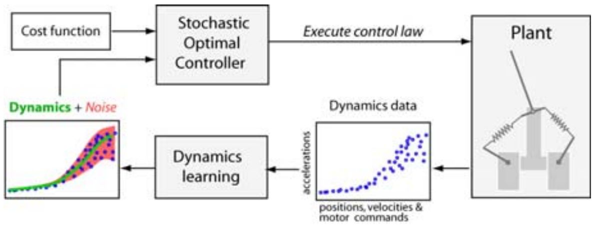

Figure 1: Stochastic optimal control with learned dynamics used to realise energy optimal impedance control.

To evaluate the scalability of our framework to real hardware, we designed and built a novel antagonistic series elastic actuator (SEA) characterised by a simple mechanical architecture. This SEA achieves variable stiffness using linear springs and changing arm moments at the links and the actuators (Figure 2). While the stiffness range of our setup is much smaller compared to other proposed systems, it suffices to study the effects of variable impedance on the learning stochastic information. We ran rigorous evaluations on a variety of reach and hold tasks. These results highlight, for the first time on real hardware, how impedance modulation profiles tuned to the plant dynamics emerge from the first principles of stochastic optimization, achieving clear performance gains over methods that ignore or are incapable of incorporating stochastic information.

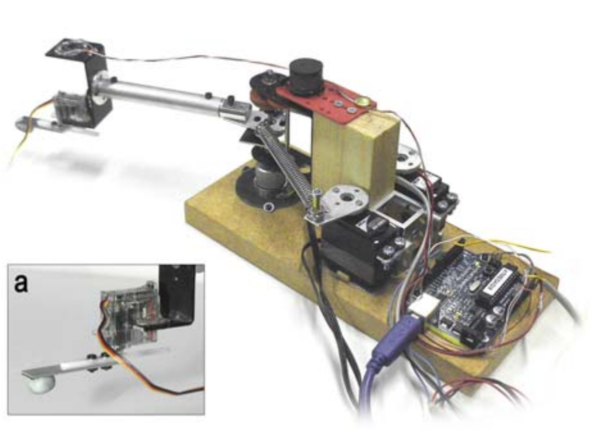

Figure 2: Proposed SEA for the study of impedance control and learning. Panel a: perturbation motor for creating stochastic perturbations on the system.