Measuring Variable Stiffness

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Abstract—The need for adaptability to the environment, energy conservation, and safety during physical interaction with humans of many advanced robotic applications has prompted the development of a number of Variable Stiffness Actuators (VSA). These have been implemented in a variety of ways, using different transduction technologies (electromechanical, pneumatic, hydraulic, but also piezoelectric, active polymeric, etc.) and arrangements with elastic elements. All designs share a fundamentally unavoidable nonlinear behavior. The control schemes proposed for these actuators typically aim at independently controlling the position (or force) of the link, and its stiffness with respect to external disturbances. Although effective feedback control schemes using position and force sensors are commonplace in robotics, control of stiffness is at present completely open–loop. In practice, instead of measuring stiffness, it is inferred from the mathematical model of the actuator. Being this in most cases only roughly known, model mismatches affect severely stiffness control, undermining its utility. It should be noticed that, while for constant stiffness elements an accurate calibration of the model is possible, the same approach is hardly viable for variable stiffness systems.

We propose a method for estimating stiffness while it is varied, either intentionally or not, hence without knowledge of the command inputs. The method uses instantaneous measurements of force and position at one of the ends of the compliant elements in the system, and derives a measure that asymptotically converges to the current value of stiffness, up to an error which can be bounded by an arbitrarily small value. Simulation and experimental results are provided, which illustrate the performance of the proposed measurement method.