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Robust energy-shaping control for robot manipulators

Natsuo Tanaka
School of Information Science,
Japan Advanced Institute of Science and Technology

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Abstract

This thesis is aimed at investigating a robust energy-shaping control for rigid robot manipulators. In many literatures concerning the manipulator control, energy-based control is an essential and natural method. An SP–D (Saturated Proportional and Differential) control method introduced in this article is one of the energy-based control. The SP–D control method is derived from a concept of energy-shaping. Investigation into the energy-shaping control is very useful for progress of the energy-based control for the manipulators. This article deals with two problems such as a tracking control in angular space and a force control in task space. In the tracking control problem, this thesis provides a robust SP–D control method against parametric uncertainties in the manipulator dynamics. In the force control problem, disturbance attenuation properties of the manipulator with an adaptive $\mathcal{H}_\infty$ SP–D controller approach are analyzed.

Firstly, a SP–D regulator presented in previous articles is extended for the tracking control problems both by adding the dynamics compensator and by modifying additional error variables. In case of no uncertainties in the dynamics compensator, the extended tracking SP–D controller ensures global asymptotic stability. By exploiting additional inputs, the tracking controller is refined to be robust against parametric uncertainties in the dynamics compensator. The additional inputs restrain undesirable perturbation caused by the parametric uncertainties. The closed-loop system with the proposed robust SP–D control law satisfies uniformly ultimate boundedness.

Secondly, the SP–D control method is applied for a force/position regulation and motion control problem. A tip of the manipulator keeps in contact with an elastic environment. That is, the force/position regulation along a constrained task direction and the motion control on a contact plane are required simultaneously. The manipulator is disturbed by unmeasurable contact forces which belong to a $\mathcal{L}_2$ space, further by the parametric uncertainties. In this thesis, an adaptive $\mathcal{H}_\infty$ approach of the SP–D control method is proposed for the above mentioned problem. The adaptive control approach is effective for the parametric uncertainties in the manipulator dynamics on one hand. On the other hand, the disturbance attenuation properties against the exerted forces on the tip is analyzed by using an induced $\mathcal{L}_2$-gain of the manipulator system. In other words, the shaped energy function of the manipulator system satisfies the Hamilton-Jacobi inequality.

Finally, the proposed control methods are confirmed on some experiments by using an actual 2 DOF direct drive manipulator.

Key Words: energy shaping, SP–D control, robustness, manipulator