Hysteresis-based robust switch for hybrid impedance–force control

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1 Introduction

Following the current industry evolution, humans are more than ever interacting with intelligent machines. In such scenarios, robot motion control should be compliant with its environment, which is often achieved through impedance control [1]. However, when moving in a contact-rich environment, direct force control methods are better suited to monitor explicit contact behavior. Hybrid impedance–force control is therefore a promising approach to achieve compliant control for tasks requiring a combination of motion and contact behaviors [2]. In-contact tasks are well-known examples requiring those two types of behaviors [3]. In this work, we propose to use hysteresis as the switching mechanism between the two control modes to achieve robust task transitioning.

2 Hybrid impedance and direct force control

Consider a rigid body system representing a robot, the dynamic equation writes

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + g(q) + \tau_{ext} = u, \tag{1}$$

where M and C are inertia and Coriolis matrices, $g(q)$ is a gravity term, τ_{ext} accounts for externally applied torques, and u is the control input. By specifying u, we may be performing either motion control or direct force control. We can use impedance control for the motion and the control law becomes

$$\begin{aligned} e &= q^d - q, \\ u_1 &= Ke + D\dot{e} + \hat{M}(q)\ddot{q}^d + \hat{C}(q,\dot{q})\dot{q} + \hat{g}(q) \end{aligned} \tag{2}$$

where $\hat{\cdot}$ denotes a model and $\cdot^d$ the reference quantity. On the other hand, assuming low speed and acceleration, direct force control could be expressed as

$$u_2 = J^T(q) f^d + \hat{g}(q) \tag{3}$$

with J the Jacobian and f^d the cartesian desired force of the end-effector.

3 Hysteretic switch for hybrid control

Our proposed approach is to smoothly balance between these two types of control to be able to control both contact and motion. The phenomenon of hysteresis is used as the mechanism to balance between motion and direct force control. Introducing a variable $\alpha \in [0,1]$ whose dynamics exhibits hysteresis, we can combine eqs. (2) and (3) to obtain

$$u = (1-\alpha)\cdot u_1 + \alpha \cdot u_2 \, . \tag{4}$$

The variable α is governed by a simple ODE that uses parametrized bifurcation to change its dynamics and switch accordingly between the two control modes. This set of equations is inspired from recent work on flexible decision-making systems [4]. In addition, bifurcation and non-linear theory are used to provide a deeper analysis of our control method to explain the dynamics of the variable within the controller.

4 Application

Eventually, our proposed method will be tested in a real system in our laboratory. It will aim at controlling an anthropomorphic hand from Shadow Robot. This system is however too complex to start developing new control methods from scratch, so we will provide an analysis of our method compared with other approaches for a simple task. This task consists of an elongated rectangle that needs to move its tip to a position x^d and apply at that point a force f^d. Further development is needed to extend this approach to more complex tasks by augmenting the number of variables and the interplay of their dynamics.

References

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