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Toward a simple implementation of robust impedance control for robot manipulator

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EXTENDED ABSTRACT

1 Introduction

The penetration of service robots has been rapidly growing due to numerous needs for automation. Typically, covid-19 pandemic resulted in the boom of automation in restaurant. Many robots are currently working in restaurant, as displayed in Figure 1a, but their task is mostly focused on serving while other labor-intensive tasks, such as cleaning table, are needed to be automated.

Figure 1b is a conceptual robot platform for the cleaning task. Due to the characteristics of the task, the use of robot manipulator is essential (Figure 1b), and along with position control, force control of the manipulator is required to deal with dinnerware on the table, which is usually fragile. The typical schemes to achieve the control objective are hybrid control and impedance control, and the simplest is hybrid control. But it could be suffered from the uncertainty of the environments, such as position/orientation of dinnerware/table, which is not avoidable and negligible due to the limitation of vision-based measurement (Figure 1b). Therefore, impedance control is promising for the task.

There are two kinds of methods to implement impedance control: dynamic-based impedance control (DB-IC) and position-based impedance control (PB-IC) [1]. Of those, PB-IC is less complex approach because it is based on the framework of position control, such as position-integral-derivative (PID) control, which is widely contained in commercial robot manipulator. However, it is well-known that PB-IC could introduce impedance inaccuracy, especially with robot/environment model uncertainty, due to the dynamic characteristics of the position control used [1].

This paper is to propose a simple (practical) implementation method for robust PB-IC that can be simply applied to commercial robot manipulator. As a position control scheme for PB-IC, we opted for a robust control law, time-delay control (TDC) [2], to reduce the effect of inherent dynamics of position control. In order to maximize the simplicity for practical implementation, the developed TDC-based PB-IC was transformed to a form of PID control using the relationship between TDC and PID control [3]. We will validate the feasibility of the proposed method through experiments with a commercial robot manipulator.

(a) for serving (b) for cleaning table

Figure 1. Service robots for automation in restaurant

2 Derivation of robust position-based impedance control

The control objective of impedance control is to achieve desired impedance between the position of robot end-effector and interaction force, as follow [1]:

$$M_d(\ddot{x}_d - \ddot{x}_r) + B_d(\dot{x}_d - \dot{x}_r) + K_d(x_d - x_r) = F_{int} \tag{1}$$

where $x_r, \dot{x}_r, \ddot{x}_r \in \mathrm{R}^n$ denote the required end-effector position, velocity, and acceleration in Cartesian space for the desired impedance, respectively; $x_d, \dot{x}_d, \ddot{x}_d \in \mathrm{R}^n$ the Cartesian desired trajectory and its time derivatives, respectively; $M_d, B_d, K_d \in R^{n\times n}$ the mass, damping and stiffness of the desired impedance, respectively; and $F_{int} \in \mathrm{R}^n$ denotes the interaction force on the environment exerted by the robot.

PB-IC means a position control for guaranteeing the actual robot end-effector position ($x \in R^n$) to track x_r. From (1), the desired impedance is perfectly attained when $x = x_r$. Note that the following error dynamics can achieve the goal $x = x_r$:

$$\ddot{x} = \ddot{x}_r + K_1(\dot{x}_r - \dot{x}) + K_2(x_r - x) \tag{2}$$

where $K_1, K_2 \in \mathrm{R}^{n\times n}$ denote the diagonal matrices which are chosen to guarantee $x_r - x \to 0$.

For position control in Cartesian space, the dynamics of robot manipulator is usually formed as follow:

$$F = M_x(\theta)\ddot{x} + N_x(\theta, \dot{\theta}) + F_{int} \tag{3}$$

where $M_x = \mathrm{R}^{n\times n}$ denote the inertia matrix in Cartesian space; $N_x \in R^n$ denote the Coriolis, centrifugal, and gravitational torque. As a position control law to achieve (2), we opted for TDC because its tracking performance and robustness with robot manipulator was verified [2]. The dynamics (2) can be rewritten as follow:

$$F = \bar{M}_x(\theta)\ddot{x} + F_{int} + H(\theta, \dot{\theta}, \ddot{\theta}) \ \text{ with } \ H(\theta, \dot{\theta}, \ddot{\theta}) = [M_x(\theta) - \bar{M}_x(\theta)]\ddot{x} + N_x(\theta, \dot{\theta}) \tag{4}$$

where $\bar{M}_x = \mathrm{J}^{-T}\bar{M}\mathrm{J}^{-1}$; $\mathrm{J} \in \mathrm{R}^{n\times n}$ denotes the Jacobian of the robot; and $\bar{M} \in \mathrm{R}^{n\times n}$ a constant diagonal matrix. From (4), for a sufficiently small time-delay L, TDC uses an estimation of $H(\theta, \dot{\theta}, \ddot{\theta})$ in (4), called as time-delay estimation [2], as follow:

$$H(t) \approx H(t-L) = F(t-L) - \bar{M}_x(t-L)\ddot{x}(t-L) - F_{int}(t-L) \tag{5}$$

By combining (2), (4) and (5), the following position control law to achieve $x = x_r$ was obtained:

$$F = \epsilon_{TDC} + F_{int} - F_{int}(t-L) \tag{6}$$

$$\text{with } \epsilon_{TDC} = \bar{M}_x[\ddot{x}_r + K_1(\dot{x}_r - \dot{x}) + K_2(x_r - x)] + F(t-L) - \bar{M}_x(t-L)\ddot{x}$$

This control law (6) is a robust PB-IC that can attain the desired impedance, represented in (1). Note that conventional position tracking ($x \to x_d$) can be also obtained in free space because $F_{int} = 0$ in free space (see (1)). Moreover, it just needs quite simple gain tunning procedure without accurate model information; only $\bar{M}$ is required to be tuned. Note that K_1 and K_2 are the design parameters to determine the behavior of error dynamics (2).

3 Simple and practical implementation

Despite its simplicity and robustness to uncertainty, the control law (6) is still inappropriate form to be easily implemented in commercial robot manipulator. Thanks to the relationship between TDC and PID control [3], ϵ_{TDC} in (6) can be transformed to a PID control form, as follow:

$$\epsilon_{TDC} = K\left(e + T_d\dot{e} + T_I\int e\right) + f_{dc}$$

$$\text{with } K = \bar{M}K_1/L\,;\ T_d = K_1^{-1};\ T_I = K_2K_1^{-1};\ \ f_{dc} = \bar{M}[\ddot{e}_i + K_1\dot{e}_i - (\dot{e}_i + K_1e_i)/L] \tag{7}$$

where $e = x_r - x$ denotes the error; and e_i denotes the initial value of the error. By combining (6) and (7), and x_r that can be calculated from (1), we can simply implement a robust PB-IC law with the framework of PID control.

4 Experimental plan

As shown in Figure 2, the experimental setup has been ready to be operated, including a commercial robot manipulator (M1013, Doosan Robotics, Korea), a table, an intuitive end-effector with a force sensor (AFT200, Aidin Robotics, Korea), and an embedded computer for implementing the control method operated by a real-time operating system (Xenomai). Note that available sampling frequency with the computer is 1 kHz (L=1ms). We will verify the feasibility of the proposed PB-IC method, in terms of the quality of impedance attained and the robustness against several expected uncertainties.

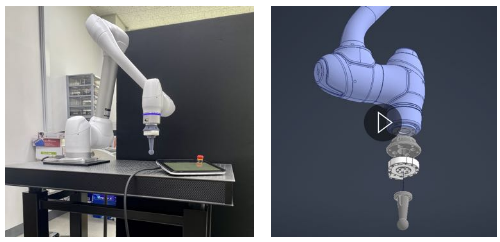

Figure 2. Experimental setup

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References

[1] T. Valency, et.al., "Accuracy/Robustness Dilemma in Impedance Control," *Trans. ASME, J. Dyn., Syst. Meas., Control*, vol. 125, pp. 310–319, Sep. 2003.

[2] T. C. Steve Hsia, et.al., "Robust independent joint controller design for industrial robot manipulators," *IEEE Trans. Ind. Electron.*, vol. 38, no. 1, pp. 21–25, Feb. 1991.

[3] S. Jung, et.al., "A Systematic Method for Gain Selection of Robust PID Control for Nonlinear Plants of Second-Order Controller Canonical Form," *IEEE Trans. Control Syst. Technol.*, vol. 17, no. 2, pp. 473–483, Mar. 2009.