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Adaptive admittance control for a safe and efficient human-robot interaction

Federica Ferraguti, Chiara Talignani Landi, Lorenzo Sabattini, Marcello Bonfè,
Cesare Fantuzzi and Cristian Secchi

***Abstract*— The possibility of adapting online the way a robot interacts with the environment is becoming more and more important. Nevertheless, stability problems arise when the environment (e.g. the human) the robot is interacting with gets too stiff. In this work, we present a strategy for handling the stability issues related to a change of stiffness of the human arm during the interaction with an admittance-controlled robot.**

I. INTRODUCTION

One of the most revolutionary and challenging features of the new generation of robots is physical human-robot interaction (pHRI). In pHRI tasks, robots are designed to coexist and cooperate with humans in applications such as assisted industrial manipulation, collaborative assembly, domestic work, entertainment, rehabilitation or medical applications. In these contexts, due to the desired coexistence of robotic systems and humans in the same workspace, main concerns are related to safety and dependability. A widely used approach consists in implementing interaction control strategies that guarantee a compliant behavior of the robot. In particular, admittance control is typically utilized for controlling industrial robots, that are generally characterized by a stiff and non-backdrivable mechanical structure [1].

For example, admittance control has been used to implement robot manual guidance in [2] and [3], by means of the "walk-through programming" where the human operator becomes the teacher that physically guides the robot throughout the desired trajectory. When using admittance-controlled robots, instability can arise when interacting with stiff environments. Since humans are dynamic systems characterized by a time-varying impedance, they can behave in a stiff way and, consequently, give rise to instability when interacting with admittance-controlled robot. Instability induces, among other undesired effects, a deviation of the robot from the desired admittance behavior. Furthermore, it produces high amplitude oscillations of the end-effector, undermining the user safety during the interaction. The deviations have to be first promptly detected and then canceled (or reduced) to restore the stability of the system. The adaptation of the parameters of the admittance control is a common strategy for recovering the stability of the interaction as shown, e.g., in [4], [5] and [6]. In this work we show a novel strategy for detecting the rise of oscillations during the interaction between a human and an admittance-controlled robot and a parametric adaptation of the admittance for restoring a stable behavior. The proposed adaptation allows to keep the adaptive dynamics similar to the nominal one in order to avoid unbalancing effects and to increase the usability of the system. Preliminary results have been presented in [7] and [8], while in [9] a method for automatically setting the detection threshold using a thorough statistical analysis has been introduced. Moreover, a weighted energy allocation strategy has been proposed in order to consider separately translations and rotations. In this work we present the overall framework and we show the experimental validation of the control architecture.

II. ADAPTIVE ADMITTANCE CONTROL

The goal of the admittance control is to force the robot to behave in a desired way when interacting with the environment. In this paper, we address the case of a robotic manipulator manually driven by the a human operator and, therefore, we consider a mass-damper system as a desired interactive behavior:

$$M_d\ddot{x}(t) + D_d\dot{x}(t) = F(t) \tag{1}$$

where $x(t), \dot{x}(t) \in \mathbb{R}^6$ are the pose and the velociy of the end-effector respectively, $M_d \in \mathbb{R}^{6\times6}$ and $D_d \in \mathbb{R}^{6\times6}$ are the desired inertia and damping symmetric and positive definite matrices. The external force $F(t) \in \mathbb{R}^6$ in (1) is assumed to be measured by a 6-DOF force/torque (F/T) sensor attached at the robot wrist flange. During the execution of the cooperative task, the robot is coupled with a human operator, whose dynamics (e.g. change of compliance of the arm) can cause deviations from the desired behavior that may produce robot oscillating motions of high amplitude and frequency, making the interaction unsafe for the user ([4]). As noticed in [4], the oscillating motion can be eliminated by increasing the desired inertia of the controlled dynamics. Nevertheless, this is a very dangerous operation since a variation of the inertia matrix can lead to a production of virtual energy and, consequently, to an increase of the amplitude of the oscillations. Thus, it can happen that while changing the inertia for reaching a more stable situation, the instability gets worse and worse.

We propose a passivity based parametric adaptation strategy for adapting the inertia in such a way that no destabilizing effects are generated. The following time-varying

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F. Ferraguti, C. Talignani Landi, L. Sabattini, C. Fantuzzi and C. Secchi are with the Department of Sciences and Methods for Engineering (DISMI), University of Modena and Reggio Emilia, Italy `{name.surname}@unimore.it` M. Bonfè is with the Engineering Department, University of Ferrara, Italy `marcello.bonfe@unife.it`

interaction model is implemented

$$M(t)\ddot{x}(t) + D(t)\dot{x}(t) = F(t) \tag{2}$$

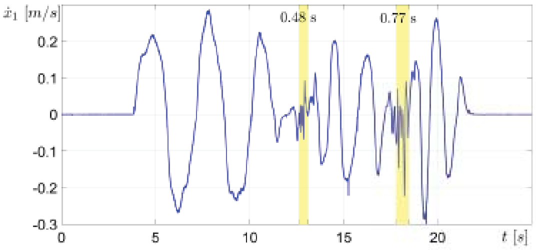
where $M(0) = M_d$ and $D(0) = D_d$.

The proposed approach consists of two main steps: the detection of rising oscillations and the implementation of a stable adaptation.

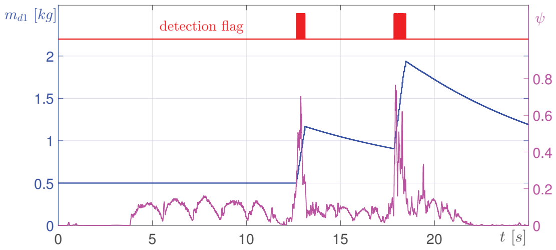
In order to detect the rise of an oscillatory behavior, that would make the system unsafe and unusable, an index $\psi(t)$ representing the difference between the behavior commanded by the desired admittance dynamics (1) and the real behavior is defined. By monitoring the evolution of ψ, it is possible to detect the rise of the unstable behavior and to activate the adaptation procedure. In order to implement a stable adaptation, the concept of energy tank is exploited. The interacting dynamics (2) is augmented by a virtual energy tank which stores/releases the energy due to the variation of the parameters. If a dissipative parametric variation takes place (e.g. an increase of the damping $D(t)$), the the dissipated energy is stored in the tank. If a regenerative parametric variation takes place (e.g. an increase of the inertia $M(t)$), the generated energy is extracted form the tank. As long as some energy is available in the tank, the inertia can be increased without producing destibilizing effects. Thus, the amount of energy stored in the tank is linked to the maximum possible (safe) increase of the inertia. Given a desired increase of the inertia and the energy stored in the tank, it is possible to plan a safe increase of the inertia for stabilzing teh oscillatory behavior. If the available energy is not sufficient for implementing the desired increase, it is possible to augment the damping for filling the tank. Once the oscillatory effects have been compensated, a forgetting factor for restoring the desired inertia M_d is implemented.

III. EXPERIMENTS

The experiments have been performed restricting robot motion to only one translational DOF. The inertia and damping initial parameters have been set equal to $m(0) = 0.5\ kg$ and $d(0) = 5\ {}^{Ns}/_{m}$, since these values have been found in [4] to be the minimum stable admittance gains for a KUKA LWR 4+, which is also the robot used in our experiments. Whenever the user excessively stiffens his/her arm, high-frequency oscillations appear in the velocity of the robot (Figure 1(a)). Figure 1(b) shows, in magenta, the evolution over time of the detection index $\psi(t)$.. A boolean detection flag is depicted with a red line in Figure 1(b). As it can be seen, the rising oscillations are rightly detected and the inertia (blue line) is adapted accordingly. As shown in Figure 1(a), when an oscillating behavior arises (yellow regions), the adaptation of the parameters allows to stabilize the system $0.48\ s$ after the occurrence of the first oscillation and $0.68\ s$ after the occurrence of the second oscillation. Obviously, the difference in the adaptation times is due to the different attitude of the operator during the interaction, the different amplitude of the oscillations and, finally, to the starting values of the parameters when the adaptation is performed. However, thanks to a usability study we could verify that, from the user perspective, all the adaptation periods were sufficiently short amounts of time, since the adaptation of the parameters was achieved before the user could actually feel the rising oscillations.



(a) Velocity of the robot along the considered translational DOF



(b) Evolution over time of the detection index $\psi(t)$ (magenta line), and of the subsequent inertia adaptation (blue line). A detection flag (red line) is added to show when the heuristic detects that oscillations are rising.

Fig. 1. Detection and adaptation of the rising oscillations using the proposed method.

REFERENCES

[1] L. Villani and J. De Schutter, "Force control," in *Springer Handbook of Robotics*, B. Siciliano and O. Khatib, Eds. Springer Berlin Heidelberg, 2008, ch. 7.

[2] C. Talignani Landi, F. Ferraguti, C. Secchi, and C. Fantuzzi, "Tool compensation in walk-through programming for admittance-controlled robots," in *Proceedings of the Annual Conference of IEEE Industrial Electronics Society*, Firenze, Italy, 2016.

[3] F. Ferraguti, C. Talignani Landi, C. Secchi, C. Fantuzzi, M. Nolli, and M. Pesamosca, "Walk-through programming for industrial applications," *Procedia Manufacturing*, vol. 11, pp. 31–38, 2017.

[4] F. Dimeas and N. Aspragathos, "Online stability in human-robot cooperation with admittance control," *IEEE Transactions on Haptics*, vol. 9, no. 2, pp. 267–278, 2016.

[5] A. Campeau-Lecours, M. Otis, P. Belzile, and C. Gosselin, "A time–domain vibration observer and controller for physical human–robot interaction," *Mechatronics*, vol. 36, pp. 45–53, June 2016.

[6] A. Lecours, B. Mayer-St-Onge, and C. Gosselin, "Variable admittance control of a four-degree-of-freedom intelligent assist device," in *Proceedings of the IEEE International Conference on Robotics and Automation*, Minnesota, USA, 2012.

[7] C. Talignani Landi, F. Ferraguti, L. Sabattini, C. Secchi, and C. Fantuzzi, "Admittance control parameter adaptation for physical human-robot interaction," in *Proceedings of the IEEE International Conference on Robotics and Automation*, Singapore, 2017.

[8] C. Talignani Landi, F. Ferraguti, L. Sabattini, C. Secchi, M. Bonfè, and C. Fantuzzi, "Variable admittance control preventing undesired oscillating behaviors in physical human-robot interaction," in *Proceedings of the IEEE International Conference on Intelligent Robots and Systems*, Vancouver, Canada, 2017.

[9] F. Ferraguti, C. T. Landi, L. Sabattini, M. Bonf, C. Fantuzzi, and C. Secchi, "A variable admittance control strategy for stable physical humanrobot interaction," *The International Journal of Robotics Research*, vol. 38, no. 6, pp. 747–765, 2019.