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Null-space Impedance Control with Disturbance Observer

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***Abstract*—In this paper a new approach for the null-space impedance control of a kinematically redundant robot is proposed. The approach is useful for the case where the robot experience an external interaction on the body, especially in the presence of humans. The proposed algorithm guarantees safe and dependable physical interaction of the robot body with the environment, thanks to the null-space impedance control. At the same time, the correct execution of the task assigned to the end effector is ensured by a disturbance observer. The algorithm does not require joint torque measurements. The performance of the proposed controller is verified through simulations on 7R KUKA lightweight robot arm.**

I. INTRODUCTION

One of the current trends in robotics is to develop new robots and control algorithms for doing daily life applications. While the industrial robots are stiff with high impedance, the robots used in dynamic environments (human environments) must be designed with high degree of safety and compliance. This compliance is useful for the applications including physical Human-Robot Interaction (pHRI) [1,2], such as service and medical robotics. In these applications not only unexpected impacts between robot and humans are likely to happen, but also intentional physical interaction with robot maybe required. To this end, different strategies may be thought. Collision avoidance is the safest approach. However, it is usually based on exteroceptive sensors such as camera which makes it inappropriate during fast interaction. Nevertheless, fast collision detection algorithms based on suitable observers also exists [3]. Alternatively, the other approach is to increase the robot compliance. Compliance can be introduced passively by using elastic decoupling between the actuator and the driven link (variable joint stiffness) [4], or actively by relying on fast control loops [5]. Note that, correct execution of the operational task during interaction is also appealing and important.

Impedance control represents a very suitable framework for controlling robots in contact with an unknown environment. The problem of impedance control has been extensively studied in the literature. The compliant behavior usually is given to the operational task to control the interaction of the end effector [6]. However, the impedance behavior can be imposed also in the joint space to ensure safe interaction [7-9].

Recently, problems and solutions related to kinematic redundancy have obtained new interest because of the application of robotic systems with high degree of freedom, such as humanoid and dual-arm robots. One approach to deal with this redundant degrees is multi-priority control, that is a well-established framework and can be performed both in kinematic [10,11] and dynamic level [12,13]. With this formulation for instance it is possible to control the behavior of several interaction points on the body of the robot, if the contact points are known a priori.

The Cartesian impedance control for torque controlled lightweight robots was investigated in [6]. Later in [14], the impedance control problem accompanied with the null-space stiffness implementation for DLR 7DOF flexible joint arm, based on singular perturbation approach, was addressed.

Multi-priority Cartesian impedance control has been investigated in [15], where several impedances in the Cartesian space are realized with a specified order of priority. Recently in [16] the multi-priority control has been considered for a case where the second priority joint space impedance operates in the null-space of the first priority Cartesian impedance of the end effector.

In [3,17] an efficient method was presented that enables fast collision detection and safe reaction based on generalized momentum of the robot, without using any torque sensor. Later in [18], safety issues were considered and several reaction strategies were presented and validated by experiments. Also the redundancy of the robot was exploited to preserve as much as possible the execution of the end effector task by projecting the reaction torques into the null-space of the main task [19].

The problem of force sensor-less disturbance rejection was investigated in [20] for robot manipulators. A force estimator is used to compensate external force disturbance that is applied on the end effector. The method later has been extended to the case where parametric uncertainties also exist despite the unknown external disturbance on the end effector [21].

Null-space impedance as a result of multi-priority control in acceleration level was presented in [13]. The approach was motivated by the idea of having control over the interaction of the robot body with the environment in the joint space in spite of the task space control by exploiting

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