Task-Space Control of Robot Manipulators With Null-Space Compliance

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***Abstract*—In this paper, the problem of controlling a robot manipulator in task space, while guaranteeing a compliant behavior for the redundant degrees of freedom, is considered. This issue may arise in the case where the robot experiences an interaction on its body, especially in the presence of humans. The proposed approach guarantees correct task execution and compliance of the robot's body during intentional or accidental interaction in the null space of the main task, simultaneously. The asymptotic stability of the task-space error is ensured by using suitable observers to estimate and compensate the generalized forces acting on the task variables, without using joint torque measurements. Two different controller–observer algorithms are designed, and they are based on the task-space error and on the generalized momentum of the robot, respectively. The performance of the proposed algorithms is verified in experiments on a 7R lightweight robot arm.**

***Index Terms*—Disturbance observer, null-space compliance, task-space control.**

I. Introduction

NEW applications where robots are employed near humans are growing rapidly. Unlike the industrial robots, which are stiff to guarantee high precision, the robots used in anthropic environments must be designed with high degree of compliance to ensure safety. This is especially true for the applications requiring physical human–robot interaction [2], not only because of unexpected impacts of robots with humans but for the execution of collaborative tasks requiring intentional exchange of forces as well.

A safe human–robot coexistence can be guaranteed combining different strategies. The safest approach is to avoid any unwanted collisions. This, however, can be achieved using exteroceptive sensors such as cameras that are ineffective in the case of fast interaction. Hence, appropriate collision detection and reaction strategies must be adopted [3]. A possibility is that to cover the manipulator body with a sensitive skin to detect and/or measure the interaction forces. Alternatively, suitable observers can be used to estimate the collision forces from joint positions or torques [4], [5]. For this purpose, an effective approach based on the computation of the generalized momentum of the robot, without using any torque sensors, was proposed in [6]. The reaction strategies are aimed at immediately removing the robot from the collision area. Nevertheless, in the case of redundant robots, it is possible 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 [7].

Robot compliance is useful in order to reduce the interaction forces, both in the case of collision and during physical collaboration between humans and robots [8]. Compliance can be introduced passively by using elastic decoupling between the actuator and the driven link with fixed or variable joint stiffness [9] or actively by relying on fast control loops [10].

Impedance control represents an effective approach to control actively the robot's compliance. The impedance behavior usually is given to the task variables to control the interaction of the end effector [11]–[13], also during the execution of visual servoing tasks [14]. However, an active compliance behavior can be also imposed to the joint variables to enhance safety [15]–[18]. The Cartesian impedance control for torque controlled flexible joint and redundant robots was investigated thoroughly in [19]. The impedance control problem with null-space stiffness control for 7 degree-of-freedom (DOF) flexible joint arms, based on singular perturbation approach and passivity based approach was addressed in [20] and [21], respectively.

Recently, problems and solutions related to kinematic redundancy have gained new interest because of the application of robotic systems with a high number of DOFs, such as humanoid and dual-arm robots. A theoretical and empirical evaluation of different operational space control techniques for redundant manipulators has been presented in [22]. A well-established framework to deal with highly redundant robots is multipriority control, which can be performed both at the kinematic [23], [24] and dynamic levels [25], [26]. Within this framework, it is possible to control the behavior of several interaction points on the body of the robot.

Multipriority Cartesian impedance control has been investigated in [27], where multiple impedances with a specified order of priority are realized in the Cartesian space. A similar approach has been proposed in [28] and [29] to achieve an impedance control for the joint variables in the null space of a Cartesian impedance control imposed to the end effector.

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