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Global Impedance Control of Dual-Arm Manipulation for Safe Interaction ⋆

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Abstract: The impedance control of dual-arm 7-DOF cooperative manipulators is considered in this paper. Global compliant behavior for the whole system is achieved using impedance at three levels, i.e. object, end-effector and body level. A centralized impedance control strategy is provided to confer a compliant behavior to the object, while an active decentralized impedance control with force tracking is enforced to the end-effectors to control the internal forces on the object. A compliant behavior for the body of the dual-arm system is obtained by means of null-space impedance control. The manipulability measure of the whole system is locally maximized within this algorithm. The developed control scheme is verified in a simulation environment composed of two cooperating 7-DOF KUKA lightweight arms carrying a common object.

Keywords: Impedance control, Null-space impedance, Redundant cooperating manipulators.

1. INTRODUCTION

The interest in cooperative manipulators has grown over the years because of their utility in performing all those tasks that cannot be easily executed by a single robot arm. The fields of application can be in domestic environments as well as in flexible manufacturing systems for tasks that include handling large, heavy, or nonrigid objects, assembly of multiple parts, and all the typical tasks that humans perform using two arms. In unstructured human-shared environment a crucial issue is to achieve a compliant behavior when interaction occurs in order to realize a proper and safe cooperation between humans and robots. During the execution of a manipulation task, unexpected or pre-planned interactions of the object with the environment may occur. The main goal of the control is to ensure that the exchanged forces between the object and the environment and the internal forces applied to the object by the robotic system remain limited. In some cases, like in robotic hand manipulation, one can be interested on controlling internal forces. In this framework, several strategies have been proposed to control both absolute motion and internal forces, that can be classified as force/motion control schemes, see e.g. Wen and Kreutz (1992); Liu and Arimoto (1998); Caccavale et al. (2000). Alternative approaches can be pursued based on the well-known impedance concept of Hogan (1985). Impedance control schemes for cooperative manipulators have been proposed by Schneider and Cannon (1992) for controlling object/environment interaction forces, and by Bonitz and Hsia (1996) for controlling the internal forces. In Caccavale and Villani (1999); Caccavale et al. (2008), those strategies have been combined in a unique control framework, aimed at controlling both the contact forces due to object/environment interaction (external impedance) and the internal forces due to manipulators/object interaction (internal impedance).

A compliant behavior of the dual-arm also at the body level is useful when the robots work in a cluttered environment and interaction between the robot's body and the environment may occur. For this purpose, null-space impedance can be realized in joint space using the null-space of the main task as in Sadeghian et al. (2011). By a proper choice of null-space impedance matrices, it is possible to achieve a compliant behavior for the whole body of cooperative system. The desired trajectory for the null-space impedance equation can be chosen as a rest point or as a gradient of a given objective function. In order to achieve better performance for the cooperative manipulation system, an important issue is the definition of quantitative measures for multi-arm cooperation. One is the manipulability measure which have been widely used in robotics. An extension of manipulability analysis to multiple cooperating robots has been studied in Chiacchio et al. (1991), where the concepts developed in Yoshikawa (1985) and Chiu (1988) are formally extended to a multiarm system by taking advantage of the global task space kinetostatic formulation.

This paper extends the work of Caccavale and Villani (1999) by including a null-space impedance in series with an internal and external impedance. It is assumed that a common rigid object is rigidly grasped by the two manipulators. A 6-DOF impedance behavior with force tracking is imposed at each end-effector to control internal forces and a 6-DOF impedance behavior is imposed to the object to achieve compliance when interaction with the external environment occurs. Finally, a compliant behavior of the whole body is enforced in the null-space of the main task. The manipulability of cooperative system is also locally maximized by null-space impedance control. The developed control scheme is tested in a simulation environment comprising two 7-DOF KUKA lightweight robot arms carrying

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