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Multi-Priority Control in Redundant Robotic Systems

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Abstract—**This paper presents a dynamic level control algorithm to meet simultaneously multiple desired tasks based on allocated priorities for redundant robotic systems. It is shown that this algorithm can be treated as a general framework to achieve control over the whole body of the robot and some of the previously developed results are formalized using this approach. Null-space impedance control is proposed as one of the main results of using this method and is evaluated by means of computer simulation.**

I. INTRODUCTION

ROBOTS are termed kinematically redundant when they possess more degrees of freedom than those necessary to achieve a desired task. Redundant degrees of freedom can be conveniently used to perform some additional tasks besides the main task. These additional tasks can be a performance objective or for example a given Cartesian position of a point on the body of robot. There are plenty of papers that deal with how to use redundancy effectively to optimize some performance objective besides the main task control. This optimization is usually performed in the null-space of the main task to ensure its perfect tracking. In order to solve the conflict between tasks in the case where several objective functions are going to be satisfied simultaneously, the so-called task priority strategy developed in [1,2] is adopted. The formulation has later been extended in a general framework for managing multiple tasks by Siciliano and Slotine [3].

This formulation uses first-order differential kinematics equation and solves redundancy in the Least-Squares (LS) sense, based on the assigned priority by resorting to pseudo-inverse solution. Because of using the pseudo-inverse of the *projected Jacobians* –the Jacobians of the lower-priority tasks that are projected into the null-space of the higher-priority tasks– the formulation may suffer from high norms during transition into and out of algorithmic singularities. Usually singularity-robust pseudo-inverse that allows limiting joint velocities at the expense of small tracking error in lower priority tasks is the first remedy to treat this problem. Efficient damping techniques have been suggested by Nakamura and Hanafusa [4] and Wampler [5] and also by Nenchev et al [6] for the case of multiple priorities.

Chiaverini [7] proposed the singularity-robust task-priority resolution without using the projected Jacobian. This formulation always involves tracking errors in the additional tasks but singularities do not occur as long as the Jacobian of each additional task is full rank. The stability of this formulation has been shown in [8].

De Santis et al [9] apply the concept of Multi Point Control and Virtual End-Effectors (VEEs) for Human-Robot Interaction (HRI). The VEEs are parts of the manipulator structure, whose positions are to be controlled in addition to the control of the end-effector of the robot manipulator. They proposed a nested closed-loop inverse kinematics algorithm, with a priority management strategy in order to control robot in a cluttered environment.

Instead of velocity-based control, acceleration-based control computes the desired joint accelerations for given task references. Synthesis of joint acceleration in a redundant robot usually requires a more involved analysis, but for second-order system such as robots this formulation is the most natural and offers improved tracking ability due to the explicit incorporation of acceleration information.

The problem of internal instability at the acceleration level was first noticed by Hsu et al [10]. De Luca et al [11] presented different methods for solving robot redundancy at the acceleration level. A complete theoretical and empirical evaluation of different dynamic methods has been investigated in [12].

There are a few papers that use multi-priority control at dynamic level. Khatib et al [13,14] proposed the extension of the operational space formulation [15] to control the behavioral primitives in a humanoid robot at torque level.

Recently Platt et al [16] proposed multi-priority Cartesian impedance control by resorting to acceleration resolution.

This paper investigates multi-priority control at the acceleration level for redundant robotic systems and establishes a general framework to achieve dynamic control over the whole body of robot. It is shown that by a proper choice of the additional tasks it is possible to derive previous results in the literature within this framework. Null-space impedance control, as a result of task prioritization, together with the possible solution to cope with singularities, is presented as a main result of this work. The paper is organized as follows. In Section II the multi-priority resolution at the velocity level is briefly described. The main results, including acceleration level multi-priority control,

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