Robotica (2013) volume 31, pp. 1155–1167. © Cambridge University Press 2013
doi:10.1017/S0263574713000416

Dynamic multi-priority control in redundant robotic systems[1]

Hamid Sadeghian†,‡*, Luigi Villani‡, Mehdi Keshmiri† and Bruno Siciliano‡

†*Department of Mechanical Engineering, Isfahan University of Technology (IUT), Isfahan 84156-83111, Iran*
‡*PRISMA Lab, Dipartimento di Ingegneria Elettrica e Tecnologie dell'Informazione, Università di Napoli Federico II, Italy*

(Accepted April 15, 2013. First published online: May 22, 2013)

SUMMARY
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. The control law is an extension of the well-known acceleration-based control to the redundant robots, and considers also possible interactions with the environment occurring at any point of the robot body. The stability of this algorithm is shown and some of the previously developed results are formulated using this approach. To handle the interaction on robot body, null space impedance control is developed within the multi-priority framework. The effectiveness of the proposed approaches is evaluated by means of computer simulation.

KEYWORDS: Redundant robots; Multi-priority control; Null space impedance control.

1. Introduction

Robots are termed kinematically redundant when they possess more degrees of freedom (DOF) 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 robot body. 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 was developed.[2,3] The formulation was later extended in a general framework for managing multiple tasks by Siciliano and Slotine.[4]

This formulation uses the 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,[5] Wampler,[6] and also by Nenchev and Sotirov[7] for the case of multiple priorities.

Chiaverini[8] 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 also shown.[9]

De Santis *et al.*[10] 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.

To address dynamic uncertainties of the system, an adaptive multi-priority control has been proposed by the authors.[11] By this method, asymptotic stability and convergence of tracking error are achieved for the main task as well as the subtasks, according to the allocated priority.

Instead of velocity-based control, acceleration-based control computes the desired joint accelerations for given task references.[12] Synthesis of joint acceleration in a redundant robot usually requires a more involved analysis, but for systems such as robots, this formulation is most natural and offers improved tracking ability due to the explicit incorporation of acceleration information.

The problem of internal instability in the acceleration-level redundancy resolution was first noted by Hsu *et al.*[13] The nature of this instability was further analyzed[14] and it was shown that the divergence of joint velocity norm in finite time in linear acceleration-based redundancy resolution is possible because of rapid increase in the null space component of joint velocities. A complete theoretical and empirical evaluation of different dynamic methods has been investigated by Nakanishi *et al.*[15]

* Corresponding author. E-mail: h.sadeghian@me.iut.ac.ir
[1] A preliminary version of this paper appeared in the proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, 2011.