Modellierung und Regelung komplexer dynamischer Systeme

Band 17

**Thomas Wimböck**

# Controllers for Compliant Two-Handed Dexterous Manipulation

Shaker Verlag
Aachen 2013

**Bibliographic information published by the Deutsche Nationalbibliothek**
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Wien, TU, Diss., 2013



Printed in Germany.

ISBN 978-3-8440-1724-3
ISSN 1866-2242

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen
Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9
Internet: www.shaker.de • e-mail: info@shaker.de

# Abstract

Dexterous manipulation of large classes of objects demands large capacities from robotic systems. Most important are versatility, adaptability, and sensitivity. Robots comprised of two arms with two-jaw grippers as end-effectors have been used widely to solve various tasks. Recently, systems equipped with dexterous hands were developed, which exhibit a greater adaptability and promise a wider range of applications. The increased sensitivity of the dexterous hand together with its lower joint friction compared to arm joints is expected to enhance the overall functionality of the two-handed system.

Previous works on the control of two-handed systems consisting of two arms equipped with dexterous hands was mostly restricted to the independent control of the arm and the hand subsystems. The coordination between fingers and arms has been barely studied. When studying the work related to the object level control of robotic hands it can be seen that several publications deal with the dynamics of hand object systems, but the practitioners typically use pure stiffness controllers ignoring all the dynamic effects. In order to further develop the field of dynamic dexterous manipulation in theory and practice, this thesis is concerned with concepts to model and control a robot consisting of an upper body with two arms equipped with dexterous hands. For such a two-handed robot, the equations of motion are derived and compliant grasping controllers for various tasks are proposed. In particular, the object level impedance control was studied in more detail and a novel controller - the static intrinsically passive controller (IPC) - was proposed. In the literature, a systematic comparison of such controllers, in particular with experimental validation is missing. In the experiments of this thesis it could be shown that dynamic effects indeed are *not negligible*. The developed object level impedance controller is used in the synthesis of an impedance controller for two-handed compliant manipulation, which includes the finger arm coordination. This is the first time that such an impedance control law was successfully implemented on a two-handed robotic system - the DLR robot *Justin*. In view of the development of the new DLR (integrated) Hand Arm System, the control of tendon driven systems with inherent mechanically

varying, respectively nonlinear, stiffness was investigated. In the field of control of variable stiffness actuators many approaches have been proposed in the literature in the last decade. However, only a few research groups are working on the control design for tendon-driven robotic hands with variable stiffness. In this context, this thesis contributes to the derivation and analysis of a controller based on motor side measurements with feed forward terms. The stability proof of the closed loop system extends the seminal work of Tomei (Tomei, 1991) to the case of tendon controlled robots with variable joint stiffness.
This thesis provides a large toolbox of high-level impedance behaviors for two-handed compliant manipulation. They range from reduced complexity (synergy) coordinates to the dexterous manipulation, which is the coordinated object level control using the fingertips of the hands combined with the control of the arms and the torso. These tools offer interfaces in generalized - mostly Cartesian - coordinates to specify the motion, the internal forces, and the closed loop behavior in terms of compliance and damping coefficients. The controllers devoted to the variable stiffness system allow in addition the adjustment of the mechanical joint stiffness, which can be advantageously used to optimize additional performance criteria demanded by a given task.
This toolbox is highly relevant for the development of space robotics and service robotics applications. Furthermore, robots designed as production assistants can benefit from these developments. The presented controllers form a control framework applicable also to the commercially available DLR-HIT Hand II, which is supported by the EU Project ECHORD, the DLR Dexhand, and the DLR crawler. The synergy controller serves as a versatile testbed to study reduced complexity concepts within the EU FP7 project THE - The Hand Embodied. The concepts related to the two-arm controllers can be used on two KUKA robot arms. The proposed impedance behaviors are useful to synthesize whole-body controllers.