Universität Stuttgart
Institut für Technische und Numerische Mechanik

Fatemeh Ansarieshlaghi

Nonlinear Control of a Very Flexible Parallel Robot Manipulator

SHAKER VERLAG

Band 73 (2022)

Nonlinear Control of a Very Flexible Parallel Robot Manipulator

Der Fakultät Konstruktions-, Produktions- und Fahrzeugtechnik
der Universität Stuttgart
zur Erlangung der Würde eines Doktor-Ingenieurs (Dr.-Ing.)
genehmigte Abhandlung

von

Fatemeh Ansarieshlaghi

geboren im Iran

Hauptberichter: Prof. Dr.-Ing. Prof. E.h. Peter Eberhard

Mitberichter: Univ.-Prof. Dipl.-Ing. Dr. Johannes Gerstmayr

Tag der mündlichen Prüfung: 27. April 2022

Institut für Technische und Numerische Mechanik
der Universität Stuttgart

2022

Schriften aus dem Institut für Technische und Numerische
Mechanik der Universität Stuttgart

Herausgeber: Prof. Dr.-Ing. Prof. E.h. Peter Eberhard

Band 73/2022

Fatemeh Ansarieshlaghi

Nonlinear Control of a Very Flexible Parallel Robot Manipulator

D 93 (Diss. Universität Stuttgart)

Shaker Verlag
Düren 2022

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.: Stuttgart, Univ., Diss., 2022

Printed in Germany.

ISBN 978-3-8440-8688-1
ISSN 1861-1651

Shaker Verlag GmbH • Am Langen Graben 15a • 52353 Düren
Phone: 0049/2421/99011-0 • Telefax: 0049/2421/99011-9
Internet: www.shaker.de • e-mail: info@shaker.de

Preface

This dissertation was written as a part of my work as a research assistant from November 2015 to November 2020 at the Institute of Engineering and Computational Mechanics (name in German: Institut für Technische und Numerische Mechanik) at the University of Stuttgart. My research was partially funded by the German Research Foundation (Landesgraduiertenförderungsgesetz) via the Cluster of Excellence SimTech at the University of Stuttgart. This support is highly appreciated.

I would like to express my heartfelt gratitude to my supervisor (Doktorvater), Prof. Dr.-Ing. Prof. E.h. Peter Eberhard, for providing me with the opportunity to conduct research at ITM. I'd like to express my appreciation to him for his patient guidance, encouragement, and advice. Prof. Eberhard has successfully balanced scientific research and educational teaching as the director of ITM. I have always found the working environment he has created to be exceptional, and I am happy and grateful to participate in it. Furthermore, I'm grateful to my co-examiner, Univ.-Prof. Dipl.-Ing. Dr. Johannes Gerstmayr, for his insightful feedback and kindness.

In addition, I'd like to express my sincere gratitude to my ITM colleagues, who all contribute to the positive atmosphere at the institute and with whom I've had a lot of fun in addition to numerous technical discussions. Prof. Dr.-Ing. Michael Hanss, Dr.-Ing. Pascal Ziegler, and Prof. Dr.-Ing. Jörg Fehr were all quite helpful.

Finally, I will be eternally grateful to my parents and family for providing me with the chances and experiences that have shaped who I am today. My heartfelt appreciation to Ehsan, my spouse, who has made several sacrifices to assist me in reaching this milestone.

Fatemeh Ansarieshlaghi
Ehningen, June 2022

– Dedicated to my parents, family and my dear husband who always supports me.

تقدیم به روح پدرم و مادر عزیز و مهربانم

که در سختی‌ها و دشواری‌های زندگی همواره یاوری دلسوز و فداکار و پشتیبانی محکم و مطمئن برایم بوده‌اند.

تقدیم به همسر مهربانم

به پاس قدردانی از قلبی آکنده از عشق و معرفت که محیطی سرشار از سلامت و امنیت و آرامش برای من فراهم آورده است.

و تقدیم به خواهران نازنینم که عطر حضورشان تکرار خوشی‌های من است.

Contents

Abstract

By growing usage of the robot manipulators specially of light-weight robots, a lot of researches are focused on their controlling. Interaction control with an environment is the most important and, at the same time, the most challenging task. Hence, this thesis investigates the model-based control of a flexible-links parallel manipulator. Here, the focus is on the dynamic modeling of a flexible multibody system and the use of this model to design a high-performance model-based controller. The main goal of this work is the interaction control of the flexible lambda-shaped robot with its environment.

To achieve this goal, we investigate the lambda robot modeling and validate the models on the robot hardware to determine the best trade-off between model accuracy and simplicity for use in real-time applications. The system's full states and end-effector position are estimated using three different observers based on the robot models. They are tested on the lambda robot to determine which one is the best observer. As a result, the nonlinear high gain observer is then used in an online controller loop for a real-time application to estimate the system's full states and end-effector position. To achieve high accuracy position control, three different controllers in the robot's joints space are designed and tested on the robot hardware and the lambda robot's simulated model. In hardware tests and simulation, the feedback linearization combination with a nonlinear observer and the reduced dynamics controller produce very close results. In the robot's workspace, two different controllers are also designed. The controllers are tested on the simulated model. The results show that the reduced dynamics controller performs best for the lambda robot in joint space and workspace.

To interact with unwanted effects of environments, a disturbance observer is designed and tested on the simulated model of the lambda robot. The lambda robot has no direct measurement of its deformation derivative, and estimations are not accurate and enough noise-free to test this approach on the hardware. Therefore, to have a desired interaction, a contact tool is designed to interact with the environment and to measure the contact force. This contact tool is modeled, and a force/position control using an impedance controller is designed to regulate interaction. Finally, the controller is validated on the simulation model of the lambda robot.

In this thesis, all of the proposed schemes are extensively tested in various scenarios and the results show that the modeling, observation, precise position control, and interaction controllers work successfully.