

Marco Ceccarelli  
Eusebio Eduardo Hernández Martínez  
*Editors*

# Multibody Mechatronic Systems

Proceedings of the MUSME Conference  
held in Huatulco, Mexico,  
October 21–24, 2014

Marco Ceccarelli

Eusebio Eduardo Hernández Martínez

Editors

# Multibody Mechatronic Systems

Proceedings of the MUSME Conference  
held in Huatulco, Mexico,  
October 21–24, 2014



Springer

*Editors*

Marco Ceccarelli  
Laboratory of Robotics and Mechatronics  
LARM  
University of Cassino and South Latium  
Cassino  
Italy

Eusebio Eduardo Hernández Martínez  
Section of Graduate Studies  
National Polytechnic Institute  
Mexico  
Distrito Federal  
Mexico

ISSN 2211-0984

ISBN 978-3-319-09857-9

DOI 10.1007/978-3-319-09858-6

ISSN 2211-0992 (electronic)

ISBN 978-3-319-09858-6 (eBook)

Library of Congress Control Number: 2014946398

Springer Cham Heidelberg New York Dordrecht London

© Springer International Publishing Switzerland 2015

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law. The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media ([www.springer.com](http://www.springer.com))

# **Mechanisms and Machine Science**

Volume 25

**Series editor**

Marco Ceccarelli, Cassino, Italy

More information about this series at <http://www.springer.com/series/8779>

# Preface

The MUSME 2014, IFToMM-FelbIM–International Symposium on Multibody Systems and Mechatronics is the fifth event of a series that was started in 2002 as a conference activity mainly for promoting these topics in South American community. The first event was held at Universidad Panamericana de la Ciudad de México, Mexico in May 2002, the second was held at Federal University of Uberlandia, Brazil in March 2005, the third was hosted at Universidad Nacional de San Juan, Argentina, in April 2008, and the fourth was celebrated at Universidad Politecnica deValencia, Spain, in October 2011. This year the MUSME event has come to SUNE0 (Sistema de Universidades Estatales de Oaxaca) at UMAR Campus Huatulco, Oaxaca, under the auspices of Instituto Politecnico Nacional (IPN) and Universidad Autonoma de Queretaro, Mexico.

The MUSME aim was decided at the funding meeting in 2002 as: a conference stimulating integration between Mechatronics and Multibody Systems Dynamics disciplines; a forum for facilitating contacts among research people and students; and a match conference for communities from IFToMM (International Federation for the Promotion of Mechanism and Machine Science) and FelbIM (Federación Iberoamericana de Ingeniería Mecánica). In addition, since the beginning it has been considered preferable to have the MUSME Symposium in a location within South America, but without neglecting the possibility to bring MUSME in other parts of the world, since it is supported both by IFToMM and FelbIM.

The aim of the MUSME Symposium is to bring together researchers, industry professionals, and students from a broad ranges of disciplines referring to Mechatronics and Multibody Systems, in an intimate, collegial, and stimulating environment. Again, in the 2014 MUSME event we received a significant attention to the initiative, as can be seen by the fact that this Proceedings volume contains contributions by authors from all over the world.

The Proceedings volume of the MUSME Symposium is published within the Springer series on MMS (Mechanism and Machine Science) and contains 53 papers that have been selected from 63 submitted papers after peer review for oral

presentation. The accepted papers cover several aspects of the wide field of Multibody Systems and Mechatronics. Special attention has been given to organizing student sessions with good works from young researchers, who are still in the formation process.

This is the first time that the Proceedings is published by Springer whereas the previous proceedings were published as CD proceedings that nevertheless are available at the hosting institutions.

We would like to express grateful thanks to the members of the International Scientific Committee for MUSME Symposium for cooperating enthusiastically for the success of the MUSME 2014 event:

Prof. Marco Ceccarelli (Chair), Italy  
Prof. Mario Acevedo, Mexico  
Prof. Jorge A.C. Ambrósio, Portugal  
Prof. Alberto Cardona, Argentina  
Prof. Osvaldo H. Penisi, Argentina  
Prof. João Carlos M. Carvalho, Brazil  
Prof. Javier Cuadrado, Spain  
Mario Fernandez Fernandez, Chile  
Prof. Manfred Husty, Austria  
Prof. Tatu Leinonen, Finland  
Prof. Vicente Mata, Spain  
Prof. Carlos Munares, Perú  
Prof. Pietro Fanghella, Italy

We thank the authors who have contributed with interesting papers in several subjects, covering many fields of Multibody Systems and Mechatronics and, additionally, for their cooperation in revising papers in a short time in agreement with the reviewers' comments. We are grateful to the reviewers for the time and effort they spent in evaluating the papers with a very tight schedule that has permitted the publication of this Proceedings volume in time for the symposium event.

We thank Rector Modesto Seara Vazquez for accepting to host the MUSME 2014 event at SUNEI. We thank our colleagues for their help at the LARM Laboratory of Robotics and Mechatronics of University of Cassino and at the ESIME Ticoman del Instituto Politecnico Nacional. We thank the Director of ESIME Ticoman, Javier Roch Soto. We thank COFAA-IPN for its economic support for some activities of the MUSME event.

We also thank the auspices of IFToMM (International Federation for the Promotion of Mechanism and Machine Science) and FelbIM (Federación Iberoamericana de Ingeniería Mecánica).

We thank the publisher and Editorial staff of Springer for accepting and helping the publication of this Proceedings volume, since the early step in 2012.

We are grateful to our families since without their patience and comprehension it would not have been possible for us to organize MUSME 2014, IFToMM-FelbIM–International Symposium on Multibody Systems and Mechatronics and this Proceedings volume.

June 2014

Marco Ceccarelli  
Eusebio Eduardo Hernandez Martinez

# Contents

<b>Kinematic and Workspace-Based Synthesis of a 2-DOF Mechanism for Haptic Applications . . . . .</b>	<b>1</b>
R. Roberts and E. Rodriguez-Leal	
<b>Fuzzy Logic Control on FPGA for Solar Tracking System . . . . .</b>	<b>11</b>
Ricardo Antonio-Mendez, Jesus de la Cruz-Alejo and Ollin Peñaloza-Mejia	
<b>Dynamic Balancing of a Nutating Planetary Bevel Gear Train. . . . .</b>	<b>23</b>
P. Fanghella, L. Bruzzone and S. Ellero	
<b>Output Stabilization of Linear Systems with Disturbances. . . . .</b>	<b>35</b>
Francisco Javier Bejarano and Jorge Dávila	
<b>Development of a Heliostat for a Solar Tower Power Plant . . . . .</b>	<b>45</b>
Jorge A. García Pitol, Alicia Hernandez Gutierrez, Manuel Toledano Ayala, Juan C.A. Jáuregui Correa, Enma V. Godoy Avendaño and Oswaldo Mendoza Herbert	
<b>Mechatronic Sizing of Ball-Screw Feed Drives . . . . .</b>	<b>55</b>
R. Hecker, D. Vicente and G. Flores	
<b>Behavior of the Robot with Vibratory Excitation . . . . .</b>	<b>67</b>
T. Majewski and D. Szwedowicz	
<b>Attitude Determination System Based on Vector Observations for Satellites Experiencing Sun-Eclipse Phases . . . . .</b>	<b>75</b>
J. Rodrigo Cordova-Alarcon, Mario A. Mendoza-Barcenas and Arturo Solis-Santome	

<b>Nonlinear Identification of Inverted Pendulum System Using Volterra Polynomials . . . . .</b>	<b>87</b>
G. Ronquillo, G.J. Ríos Moreno, E. Hernández Martínez and M. Trejo Perea	
<b>Multi-robot Exploration and Mapping Strategy in Underground Mines by Behavior Control . . . . .</b>	<b>101</b>
Antoni Mauricio, Ayrton Nieves, Yomar Castillo, Kenji Hilaraca, Christian Fonseca, Jhair Gallardo, Ricardo Rodríguez and Glen Rodríguez	
<b>Modeling Online via Clustering and Fuzzy SVM. . . . .</b>	<b>111</b>
J.C. Tovar, C.R. Mariaca and I. Álvarez Villalobos	
<b>Cylindrical Contact Force Models for the Dynamics of Roller Chain Drives. . . . .</b>	<b>121</b>
J. Ambrosio, C. Malça and A. Ramalho	
<b>A Three-Dimensional Multibody Model of a Full Suspension Mountain Bike . . . . .</b>	<b>133</b>
B. Corves, J. Breuer, F. Schoeler and P. Ingenlath	
<b>Gear Shifting Strategies Co-simulations to Optimize Vehicle Performance and Fuel Consumption. . . . .</b>	<b>143</b>
Jony J. Eckert, Fernanda C. Corrêa, Fabio M. Santiciolli, Eduardo S. Costa, Heron J. Dionísio and Franco G. Dedini	
<b>Vibration Analysis of an Offshore Platform-Like Structure Excited by Earthquake . . . . .</b>	<b>153</b>
J. Enríquez-Zárate and G. Silva-Navarro	
<b>Dynamic Parameter Identification in the Front Suspension of a Vehicle: On the Influence of Different Base Parameter Sets . . . . .</b>	<b>165</b>
L.A. Mejía, V. Mata, F. Valero, J. Ros and X. Iriarte	
<b>An Alternative Method for the Optimum Dynamic Balancing of the Four-Bar Mechanism . . . . .</b>	<b>177</b>
Mario Acevedo, Eduardo Haro and Félix Martínez	
<b>Behavior of Some Objects in Series with Dynamic Eliminators of Vibrations. . . . .</b>	<b>189</b>
Tadeusz Majewski	

**Modeling, Analysis and Simulation of 3D Elastohydrodynamic Revolute Joints in Multibody Systems. . . . .** 199  
P. Flores

**Analysis of Experimental Data from Complex Multibody System . . . . .** 211  
J.C. Jáuregui-Correa, C.S. López Cajún and Mihir Sen

**Reduced Energy Consumption in Induction Motors with Possible Mechatronic Applications . . . . .** 219  
G. Calzada-Lara and J. Álvarez-Gallegos

**Modeling and Control of a Pendubot with Static Friction . . . . .** 229  
Sergio Sánchez-Mazuca, Israel Soto and Ricardo Campa

**Design of Electronic Control Board to Obtain the Photovoltaic Module Power Voltage Curve as Temperature Function . . . . .** 241  
J. Vega-Pérez, S. Vega-Pérez and L. Castañeda-Aviña

**A Robust Control Scheme Against Some Parametric Uncertainties for the NXT Ballbot . . . . .** 249  
R.A. García-García and M. Arias-Montiel

**Fuzzy Logic Control on FPGA Using LabVIEW. . . . .** 261  
Juan Carlos García-Montalva, Jesús de la Cruz-Alejo and Jorge Díaz-Salgado

**High-Order Sliding Modes Based Linearization: An Application to Roll Autopilot . . . . .** 273  
J. Davila, A. Monsivais and A. Mosqueda

**Proposal of Automated Inspection Using Camera in Process of VIN Validation . . . . .** 285  
L.R.S. Souza, R.M.M. Oliveira and M.H. Stoppa

**Concept Design Process for Robotic Devices: The Case of an Assistive Robot . . . . .** 295  
H.A. Moreno Avalos, I.G. Carrera Calderón, S. Romero Hernández and V. Cruz Morales

**Design and Construction of a Submarine with Five Degrees of Freedom . . . . .** 305  
Ortiz R. Floriberto, Barroeta Z. Carlos and J. Francisco Novoa C

<b>Concurrent Structure-Control Design of Parallel Robots Using an Estimation of Distribution Algorithm</b> . . . . .	315
E. Chávez-Conde, S. Ivvan Valdez and Eusebio Hernández	
<b>Emulation of Mechanical Structures Through a Multi-agent Robot System: An Overview</b> . . . . .	327
J. González-Sierra and E. Aranda-Bricaire	
<b>Design and Construction of a Nouvelle Vertical Axis Wind Turbine Experimental Platform</b> . . . . .	339
Lourdes García, David Lara, Azahel Treviño, Gerardo Romero, José G. Rivera and Esmeralda Lopez	
<b>Motion Analysis of a Six-Legged Robot Using the Bennett's Linkage as Leg</b> . . . . .	349
J.C.M. Carvalho and T.R. Silvestre	
<b>Implementation of Force and Position Controllers for a 3DOF Parallel Manipulator</b> . . . . .	359
J. Casalilla, M. Vallés, A. Valera, V. Mata and M. Díaz-Rodríguez	
<b>Mechanical Reproduction of the Horse Movement from a Hippotherapy Cycle</b> . . . . .	371
C.S. López-Cajún, J.C. Jáuregui-Correa, C.A. González-Cruz and M. Rodríguez	
<b>Identification of a Cylindrical Robot Using Recurrent Neural Networks</b> . . . . .	381
Carlos Román Mariaca Gaspar, Juan Eduardo Velázquez-Velázquez and Julio César Tovar Rodríguez	
<b>New Design of Petal Type Deployable Space Mirror</b> . . . . .	391
V.I. Bujakas	
<b>Corradino D'Ascanio and His Design of Vespa Scooter</b> . . . . .	399
M. Ceccarelli and G. Teoli	
<b>Rigid Body Hyper-jerk Analysis Using Screw Theory</b> . . . . .	411
Jaime Gallardo-Alvarado and Mario A. Garcia-Murillo	
<b>Joint Trajectory Optimization Using All Solutions of Inverse Kinematics of General 6-R Robots</b> . . . . .	423
U. Kuenzer and M.L. Husty	

<b>Mill Setup Manual Aided by Augmented Reality. . . . .</b>	<b>433</b>
F. Suárez-Warden, E. González Mendivil, H. Ramírez, L.E. Garza Nájera and G. Pantoja	
<b>Dimensional Synthesis of a Planar Parallel Manipulator Applied to Upper Limb Rehabilitation . . . . .</b>	<b>443</b>
Ileana P. Corona-Acosta and Eduardo Castillo-Castaneda	
<b>Workspace Analysis of a Delta-Like Robot Using an Alternative Approach . . . . .</b>	<b>453</b>
A. Gutiérrez-Preciado, M.A. González-Palacios and L.A. Aguilera-Cortés	
<b>Adaptive Low Cost Gravity Balanced Orthosis . . . . .</b>	<b>465</b>
Giuseppe Cannella, Dina S. Laila and Christopher T. Freeman	
<b>Design and FEM Analysis of a Novel Humanoid Torso . . . . .</b>	<b>477</b>
Daniele Cafolla and Marco Ceccarelli	
<b>Nonlinear Full-Car Model for Optimal Dynamic Design of an Automotive Damper . . . . .</b>	<b>489</b>
Carlos A. Duchanoy, Carlos A. Cruz-Villar and Marco A. Moreno-Armendáriz	
<b>Design of a Parallel Mechanism for Knee Rehabilitation . . . . .</b>	<b>501</b>
B.D. Chaparro-Rico, E. Castillo-Castaneda and R. Maldonado-Echegoyen	
<b>Design and Construction of a Translational Parallel Robot for Drilling Tasks . . . . .</b>	<b>511</b>
R. Maldonado-Echegoyen and E. Castillo-Castaneda	
<b>A Solution to the Approximate Spherical Burmester Problem . . . . .</b>	<b>521</b>
Jérémie Léger and Jorge Angeles	
<b>Mechatronic Design of a Mobile Robot and Non-Linear Control . . . . .</b>	<b>531</b>
J. Hernández, J. Torres and S. Salazar	
<b>Decentralized Supervisory Control of an AMS Based on the ISA Standards . . . . .</b>	<b>543</b>
E.G. Hernandez-Martinez, S.A. Foyo-Valdes, E.S. Puga-Velazquez and J.A. Meda-Campaña	

<b>A Planar Cobot Modelled as a Differential Algebraic System. . . . .</b>	<b>555</b>
Omar Mendoza-Trejo and Carlos Alberto Cruz-Villar	
<b>Design and Implementation of an Affective Computing for Recognition and Generation of Behaviors in a Robot. . . . .</b>	<b>567</b>
Rodolfo Romero Herrera, Francisco Gallegos Funes and Maria Adela Soto Alvarez del Castillo	
<b>Author Index . . . . .</b>	<b>579</b>

# Kinematic and Workspace-Based Synthesis of a 2-DOF Mechanism for Haptic Applications

R. Roberts and E. Rodriguez-Leal

**Abstract** This paper presents the development of a mechanism aimed to haptic applications. The basic design proposed in this work is intended to interact with a finger without the use of a fixture attached to the body. This work investigates the theoretical workspace of a human index finger and proposes a two degree-of-freedom 7-bar linkage mechanism that is synthesized based on such workspace. The paper determines the closed-form solutions to the forward and inverse position, and presents a prototype that is built and tested as a proof of concept of the novel device. The workspace of the constructed mechanism is compared with theoretical models in order to assess their similarity and the viability of accelerometers as position sensing instruments is also tested.

**Keywords** Haptics • Workspace analysis • Kinematics • Human-machine interaction • Prototype

## 1 Introduction

The enhancement of the user-experience in virtual environments has been a highly studied topic in recent years [1, 2]. Audiovisual devices are capable to provide engaging interactive experiences to users, and can be classified as one-way or two-way communication systems, e.g. watching TV or playing videogames respectively. One of the most challenging issues in two-way communications is the saturation of the communication channels that result in the loss of information. To overcome this issue, a haptic device could be used as an alternative communication channel. For several decades, haptic devices have been commercially available for

---

R. Roberts (✉) · E. Rodriguez-Leal  
Tecnológico de Monterrey, Monterrey, Mexico  
e-mail: re.roberts.phd.mty@itesm.mx

E. Rodriguez-Leal  
e-mail: ernesto.rodriguez@itesm.mx

different applications, e.g. using vibrotactile actuators in cell phones and pagers [3], or guiding tools that are designed to help soldiers to navigate in battlefields [4]. Moreover, the gaming industry is a niche for haptic devices, enhancing the multimedia experiences of players and providing a new sense of realism [5]. Furthermore, force feedback haptic devices have received a special interest from the medical community including applications such as palpation, needle insertion, laparoscopy, endoscopy, endovascular procedures or arthroscopy [6].

Several of the commercial single-point force feedback devices are designed to be manipulated using an entire hand, displaying three translational degrees-of-freedom (DOF), and can be provided with three additional rotational DOF [6, 7]. Some of the benefits of this type of devices include a workspace in which comfortable movement is allowed, and a mechanism design that is low weight while is capable to provide reliable force feedback. Some of the drawbacks that are encountered in single-point force feedback devices include accuracy limitations in multiple-object simulation, which is essential for object recognition in haptics [8, 9].

This paper describes the development and synthesis of the novel haptic device and is organized as follows: Sect. 2 presents a description of the desired characteristics and features of this mechanism. Section 3 performs a thorough mathematical analysis of the mechanism. A practical approach for conducting the synthesis of the mechanism is discussed in Sect. 4, where the workspace of a human finger is used to determine the dimensional parameters of the mechanism. Section 5 discusses the prototype and validates the theoretical workspace with experimental data. Finally, the paper presents conclusions and suggestions for further work.

## 2 Mechanism Description

The new haptic mechanism proposed in this paper considers the following features: (i) compact size suitable for finger movement, (ii) non-collapsibility, (iii) low mechanical impedance. A compact apparatus is desirable since a long term goal of this project is to build a multi-point haptic device. Hence, it is important to reproduce this mechanism five times within the workspace of a hand. A non-collapsible mechanism eliminates the inclusion of components that force contact with the finger. This feature is required in cases in which movement flexibility is desired. Finally, reducing inertia and friction in the device is desired to achieve a realistic haptic experience.

Figure 1a shows the proposed seven-link and six-joint mechanism, which can be thought as two four-bar mechanisms that share a common bar. The base is connected to link 2 with links 1 and 3 with the use of joints, while the platform is connected to link 2, with links 4 and 5. Note that all the axes of the joints are parallel to each other and to the Z axis. Consider that links 1, 3, 4 and 5 have a length  $l$  while link 2, the base and the platform have a length that is equal for the three elements, although the particular value of this parameter is irrelevant as the following equations will show. The abovementioned dimensional considerations

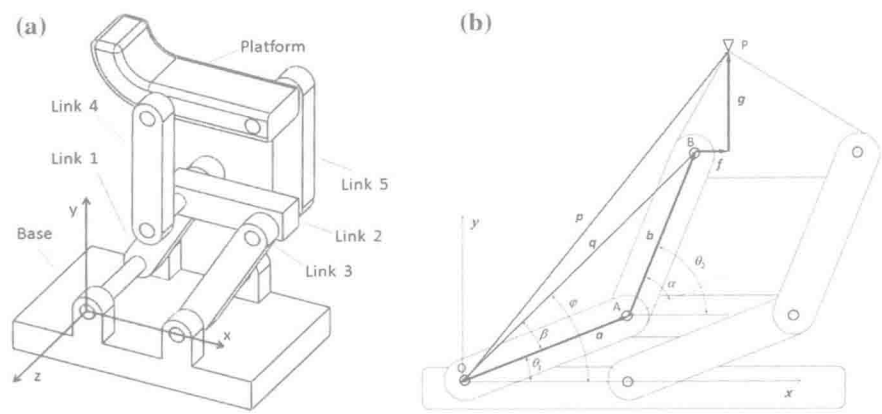


Fig. 1 a CAD model and b vector representation of the seven bar linkage

guarantee that the mechanisms comply with the Grashof condition [10]; they also assure that the base, platform, and link 2 remain parallel for all positions of the mechanism. Note that the joint connecting links 2 and 5 is active, meaning that a motor applies torque to this kinematic pair; this is also the case for the joint connecting the base and link 1. The following section includes the kinematics analysis that determines the closed-form solutions to the position, velocity and acceleration of the seven-bar mechanism.

### 3 Mechanism Kinematics

The forward *kinematics* consists in determining the position vector  $p$  of an arbitrary point P of the platform. See Fig. 1b for a vector representation of the mechanism. Note that for analysis convenience, all vectors lie on the XY plane and is possible to determine  $p$  as follows:

$$p = [lc\theta_1 + lc\theta_2 + f, \quad ls\theta_1 + ls\theta_2 + g]^T \tag{1}$$

where  $f$  and  $g$  are the magnitudes of vectors  $f$  and  $g$ .  $\theta_1$  and  $\theta_2$  denote the angular position of the active joints connected to links 1, and 4, respectively. Note that links 1 and 3 are parallel, the same is true for links 4 and 5.

The *inverse kinematics* consists in finding the magnitude of the angular positions of the active joints for a given position of the platform. Consider from Fig. 1 that vector  $q$  describes the position of point B and can be expressed as:

$$q = [lc\theta_1 + lc\theta_2, \quad ls\theta_1 + ls\theta_2]^T \tag{2}$$