# Curriculum Vitae of
# ALESSANDRO DE LUCA

**September 2011**

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# Biosketch

Alessandro De Luca was born in Roma, Italy, on October 11, 1957. He received the *Laurea* degree in Electronic Engineering and the *Research Doctorate* degree in Systems Engineering from the University of Roma "La Sapienza" in 1982 and 1987, respectively. From 1988 to 1992 he was a Researcher at the School of Engineering of the University of Roma "La Sapienza". He was then an Associate Professor of Automatic Control in the Department of Information Sciences at the University of Milano from 1992 to 1993, and in the Department of Computer and System Science (DIS) at the University of Roma "La Sapienza" from 1993 to 2000. Since 2000, he is a Full Professor of Robotics at the University of Roma "La Sapienza" where he has been the scientific responsible of the DIS Robotics Laboratory until April 2005. From September 1985 to May 1986, he was a Visiting Scholar at the Robotics and Automation Lab of the Rensselaer Polytechnic Institute, Troy, NY. From September 2005 to April 2006, he visited the Institute for Robotics and Mechatronics at DLR in Oberpfaffenhofen, Germany. His research interests include modeling, motion planning, and control of flexible manipulators, kinematically redundant manipulators, underactuated robots, wheeled mobile robots and mobile manipulators; hybrid force-velocity control; nonlinear control of nonholonomic mechanical systems; iterative learning; fault detection and isolation; visual servoing; physical human-robot interaction. Under his lead, projects of the Robotics group at DIS have been funded with many national and european research grants. He has published more than 170 journal and conference papers and book chapters. He is coeditor of the book *Advances in Control of Articulated and Mobile Robots* (Springer, 2004) and one of the authors of the awarded *Springer Handbook of Robotics* (2008). For the *IEEE Transactions on Robotics and Automation*, he served as *Associate Editor* from 1994 to 1998, as *Editor* from 1998 to 2003, and as *Editor-in-Chief* from 2003 to 2004. He has been the *Editor-in-Chief* of the renamed *IEEE Transactions on Robotics* since its birth in 2004 until September 2008. In 2005, he received the German *Helmholtz Humboldt Research Award* for foreign scientists. Since 2006, he is member of the Search Committee for Physical Sciences (former Technical Sciences) of the *Körber European Science Award*, granted by the Körber Foundation. He has served as a program committee member for numerous international conferences. He was General Chair of the *2007 IEEE International Conference on Robotics and Automation* held in Rome in April 2007. He has been a member of the *RAS AdCom* (2008–2010) and will serve as *RAS Vice-President* for Publication Activities in 2012–13. In 2009, he received the *IEEE-RAS Distinguished Service Award*. Since 2009, he is Chair of Panel PE7 (Systems and Communication Engineering) of the *European Research Council* for the Advanced Grant evaluation. He is an *IEEE Fellow* (class of 2007).

# Education

**Jul. 1987** *Research Doctorate* degree in Systems Engineering from the University of Roma "La Sapienza"

**Feb. 1984** *Master* degree in Control Systems Engineering from the University of Roma "La Sapienza"

**Nov. 1983** *Professional Engineer* certificate

**Mar. 1982** *Laurea* degree in Electronic Engineering *magna cum laude* from the University of Roma "La Sapienza"

# University Employment

**2000–pres.** *Full Professor* of Robotics at the Faculty of Information Engineering of the University of Roma "La Sapienza", Department of Computer and Systems Science; tenured since Nov. 2003

**1993–2000** *Associate Professor* of Automatic Control and Industrial Robotics at the Faculty of Engineering of the University of Roma "La Sapienza", Department of Information and Electrical Engineering; tenured since Nov. 1995

**1992–1993** *Associate Professor* of Automatic Control at the Faculty of Sciences of the University of Milano, Department of Information Sciences

**1988–1992** *Researcher* in Automatic Control at the Faculty of Engineering of the University of Roma "La Sapienza", Department of Computer and Systems Science; tenured after three years

# Visits

**Sep. 2005–Apr. 2006** *Visiting Researcher* at the Institute for Robotics and Mechatronics of DLR in Oberpfaffenhofen, Germany, under the support of the *Helmholtz Humboldt Research Award* for foreign scientists

**Nov. 1989** *Visiting Researcher* at the CINVESTAV, Mexico City, Mexico

**Sep. 1985–May 1986** *Visiting Scholar* at the Robotics and Automation Lab of the Rensselaer Polytechnic Institute, Troy, NY

# Academic Committees

## Local

**from 2010** Scientific responsible for the Exchange Agreement between the School of Information Engineering of the University of Roma "La Sapienza" and the Graduate School of Engineering of the Tohoku University in Sendai

**2010–2011** Member of the panel of experts for the quinquennial evaluation of research activities of the University of Roma "La Sapienza" (VQR 2004–2008)

**2002–2006** ERASMUS Committee for student mobility within the European Union, School of Engineering, University of Roma "La Sapienza"

**1994–pres.** Research Doctorate Committee in Systems Engineering, University of Roma "La Sapienza"

**1995–1996** Professional Engineering Qualification Committee, University of Roma "La Sapienza"

**1990–1991** Executive Committee of the Department of Computer and Systems Science, University of Roma "La Sapienza"

## National

**Jun. 2011** Committee for Doctorate Degree in Automation, Robotics, and Bioengineering, University of Pisa

**Dec. 2010** Committee for Doctorate Degree in Computer and Systems Engineering, University of Napoli Federico II

**Sep. 2010** Committee for Promotion to Associate Professor in Automatic Control, University of Lecce

**Oct. 2006** Committee for Promotion to Full Professor in Automatic Control, Politecnico of Milan

**Nov. 2004** Committee for Doctorate Degree in Computer Science and Automation, University of Roma Tre

**May 2000** Committee for Promotion to Researcher in Automatic Control, University of Roma "Tor Vergata"

**Nov. 1999** Committee for Doctorate Degree in Electronic and Computer Engineering, University of Napoli Federico II

## Abroad

**Jul. 2010** *Doktor-Ingenieurs, Karlsruher Institute für Technologie*, Karlsruhe, Germany; Giulio Milighetti, "Multisensorielle diskret-kontinuierliche Überwachung und Regelung humanoider Roboter"

**Mar. 2008** *Habilitation à Diriger des Recherches, INRIA*, Sophia Antipolis, France; Ezio Malis

**Sep. 2006** *Doktor-Ingenieurs, Technische Universität München*, München, Germany; Michael Thümmel, "Modellbasierte Regelung mit nichtlinearen inversen Systemen und Beobachtern zur Optimierung der Dynamik von Robotern mit elastischen Gelenken"

**Jan. 2006** *Habilitation à Diriger des Recherches, Laboratoire d'Analyse et d'Architecture des Systèmes du CNRS*, Toulouse, France; Thierry Siméon

**Nov. 2005** *Doktor der Ingenieurwissenschaften, Universität des Saarlandes*, Saarbrücken, Germany; Christian Ott, "Cartesian Impedance Control of Flexible Joint Manipulators"

**Oct. 2004** *Habilitation à Diriger des Recherches, Université de Nice–Sophia Antipolis*, Valbonne, France; Pascal Morin

**Sep. 2004** *Thèse de Doctorat, Institut National Polytechnic de Grenoble*, Grenoble, France; Cédric Pradalier, "Navigation Intentionnelle d'un Robot Mobile"

**Dec. 2003** *Thèse de Doctorat, Institut National Polytechnic de Toulouse*, Toulouse, France; David Bonnafous, "Exécution Réactive de Trajectoires pour Robots Mobile Non-Holonomes"

**Nov. 2002** *Habilitation à Diriger des Recherches, Université d'Evry Val d'Essonne*, Evry, France; Tarek Hamel

**Feb. 2002** *Thèse de Doctorat, École Centrale de Nantes*, Nantes, France; Mouhacine Benosman, "Commande de Bras Manipulateurs Souples et Extensions aux Systémes à Non Minimum de Phase"

**Feb. 2001** *Habilitation à Diriger des Recherches, Laboratoire d'Analyse et d'Architecture des Systèmes du CNRS*, Toulouse, France; Philippe Souères

**Dec. 1999** *Thèse de Doctorat, Université Paul Sabatier de Toulouse*, Toulouse, France; Viviane Cadenat, "Commande Référencée Multi-capteurs pour la Navigation d'un Robot Mobile"

**Jul. 1999** *Habilitation à Diriger des Recherches, Laboratoire d'Analyse et d'Architecture des Systèmes du CNRS*, Toulouse, France; Thierry Siméon

**Oct. 1998** *European Doctor Thesis, Universitat Politècnica de Catalunya*, Barcelona, Spain; Albert Castellet, "Solving Inverse Kinematics Problems Using an Interval Method"

# Teaching Activities

## Academic Courses

**from 2010** *Elective in Robotics*, 3 ECTS, Master in Artificial Intelligence and Robotics (taught in English); University of Roma "La Sapienza" (12 students/year)

**2009–2010** *Digital Control Systems*, 6 ECTS, 1st level 'Laurea' in Computer Engineering, Control Engineering, Electronic Engineering; University of Roma "La Sapienza" (15 students/year)

**2004–pres.** *Robotics II*, 6 ECTS, Master in Artificial Intelligence and Robotics (taught in English) & 2nd Level 'Laurea' in Computer Engineering, Control Engineering, Electronic Engineering; University of Roma "La Sapienza" (35 students/year)

**2003–pres.** *Robotics I*, 6 ECTS, Master in Artificial Intelligence and Robotics (taught in English) & 1st level 'Laurea' in Computer and Control Engineering, Electronic Engineering; University of Roma "La Sapienza" (60 students/year)

**2002–2003** *Automatic Control II*, 2nd Level 'Laurea' in Computer Engineering; University of Roma Tre (30 students/year)

**2001–2003** *Automatic Control*, 1st level 'Laurea' in Computer Engineering, Electronic Engineering; University of Roma "La Sapienza" – Site of Latina (15 students/year)

**2000–pres.** *Modeling and Control of Flexible Structures*, PhD course in "Systems Engineering"; University of Roma "La Sapienza" (10 students/year, course taught on alternate years)

**1994–1998** *Control Systems I*, Master in "Theory and Methods for Systems Analysis and Control"; University of Roma "La Sapienza" (10 students/year)

**1993–2001** *Automatic Control*, 'Laurea' in Computer Engineering; University of Roma "La Sapienza" (200 students/year)

**1993–1994** *Operation Research*, 'Laurea' in Information Science; University of Milano (150 students/year)

**1992–2004** *Industrial Robotics*, 'Laurea' in Computer Engineering, Electrical Engineering, Electronic Engineering, Mechanical Engineering; University of Roma "La Sapienza" (35 students/year)

**1992–1994** *Control of Industrial Processes*, 'Laurea' in Information Sciences; University of Milano (30 students/year)

**1989–1992** *Adaptive Control*, Master in "Theory and Methods for Systems Analysis and Control"; University of Roma "La Sapienza" (10 students/year)

**1988–1989** *Systems Theory*, Master in "Theory and Methods for Systems Analysis and Control"; University of Roma "La Sapienza" (10 students/year)

# External Courses

**Jul. 2010** Lectures on "Modeling and Control of Robots with Elastic Joints" and "Safe Physical Human-Robot Interaction", *CIRA National Doctorate School on Robotics*, Bertinoro, Italy

**Jan. 2010** Lecture on "Detection and Isolation of Faults and Collisions in Robot Arms", *Doctorate School in Information Science and Engineering*, Bologna, Italy

**Apr. 2007** ICRA'07 Tutorial on "Nonlinear Control of Flexible Joint Robots", *2007 IEEE Int. Conf. on Robotics and Automation*, Roma, Italy

**Jul. 2003** Lectures on "Robots with Elastic Joints: Modeling and Control" and "Robots with Flexible Links: Modeling and Control", *CIRA National Doctorate School on Control of Robotic Systems*, Bertinoro, Italy

**Feb. 2000** Lecture on "Kinematics and Motion Generation for Wheeled Mobile Robots", *International School RoboCup 2000 Camp*, Padova, Italy

**Jun. 1996** Lectures on "Decoupling and Feedback Linearization of Robots with Mixed Rigid/Elastic Joints" and "Nonholonomic Behavior in Redundant Robot Arms", *DISC Summer School on Applications of Modern Nonlinear Control Theory*, Zeist, Netherlands

**Jul. 1994** Lectures on "Control of Nonholonomic Mechanical Systems", *Advanced Professional School on Kinematics and Dynamics of Multi-Body Mechanical Systems*, International Center for Mechanical Sciences (CISM), Udine, Italy (see [BC-3] in the list of publications)

**Sep. 1992** Lectures on "Control of Rigid Robots: Robots in Contact with the Environment" and "Control of Flexible Robots: Modelling of Robots with Flexible Links", *Summer School on Theory of Robot Control*, École Nationale Supérieure d'Ingénieurs Electriciens de Grenoble, Laboratoire d'Automatique de Grenoble (LAG-ENSIEG), Saint Martin d'Hères, France (this course was the basis for the 12-author Springer book on "Theory of Robot Control", see [BC-5] and [BC-6] in the list of publications).

**Jun. 1992** Lectures on "Fundamentals of Automatic Control and Robotics", *Tecnopolis*, Valenzano, Bari, Italy

**Mar. 1990** Lectures on "Nonlinear Control" (second edition), *Carl-Cranz Gesellschaft*, Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR), Oberpfaffenhofen, Germany

**Nov. 1989** Course on "Nonlinear Control Techniques for Robot Manipulators and Induction Motors", *IX School of the Mexican Association of Automatic Control*, Centro de Investigacion y de Estudios Avanzados (CINVESTAV), Instituto Politecnico National, Mexico City, Mexico

**Aug. 1987** Lectures on "Nonlinear Control", *Carl-Cranz Gesellschaft*, Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR), Oberpfaffenhofen, Germany

**Feb. 1987** Tutorial on "Robot Manipulators: An Application of Nonlinear Control Methods" for the course "Nonlinear Control Theory", *2nd Workshop on Mathematics in Industry*, Centro Internazionale di Fisica Teorica, Trieste, Italy

# Supervision of Students

**1993–pres.** Advisor of 7 PhD theses in Systems Engineering; University of Roma "La Sapienza"

- **2008–2011** Fabrizio Flacco (on-going)
- **2004–2007** Paolo Robuffo Giordano, "Visual Estimation and Control of Robot Manipulating Systems"
- **2002–2005** Riccardo Farina, "Trade-off between Precision and Operative Safety in Robots with Intrinsic Compliance"
- **1998–2001** Alessandro Bettini, "Task and Joint Control of Human-Robot Collaborative Systems"
- **1998–2001** Stefano Iannitti, "Motion Planning and Control of a Class of Underactuated Robots"
- **1997–2001** Fabio Maria Antoniali, "A Novel Bayesian Approach to Mobile Robot Localization"
- **1993–1996** Raffaella Mattone, "Una Metodologia Generale per la Modellazione Orientata al Compito ed il Controllo di Sistemi Robotici Cooperanti" (in Italian)

**1992–pres.** Supervisor of about 80 2nd Level 'Laurea' thesis (5-year Engineering curriculum) in Computer Engineering, Electronic Engineering, Mechanical Engineering, Systems Engineering; University of Roma "La Sapienza"

**1992–1994** Supervisor of 7 'Laurea' thesis in Information Sciences; University of Milano

The above students have performed their final work in the Robotics Laboratory of the Department of Computer and System Science (DIS), in Italian branches of industries (ABB, Oerlikon Contraves), or in international institutions (Fraunhofer IPA/IOSB Stuttgart, Fraunhofer IITB Karlsruhe, Örebro University)

# Scientific Activities

## Principal Investigator in Research Groups

### European

**2011–2015** Coordinator of 7th FP IP Project 'Safe and Autonomous Physical Human-Aware Robot Interaction (SAPHARI)" supported by the *European Commission*

**2006–2009** 6th FP STREP Project 'Physical Human-Robot Interaction: Safety and Dependability (PHRIENDS)" supported by the *European Commission*

**2006** Perspective Research Project 'Physical Human-Robot Interaction in Anthropic Domains (PHRIDOM)" supported by the *European Commission* within the EURON network

**2005–2008** 6th FP STREP Project "The CyberCarpet – Enabling Omni-directional Walking in Virtual Worlds (CyberWalk)" supported by the *European Commission*

**2002–2004** Integrated Project EU-IST-2001 "Intelligent Fault Tolerant Control in Integrated System (IFATIS)" supported by the *European Commission*

**2000–2003** European Robotics Research Network (EURON) supported by the *European Commission*

**1994–1996** European Robotics Network (ERNET) of the Human Capital and Mobility Programme supported by the *European Commission*

**1992–1995** ESPRIT III Basic Research Action "Planning Robot Motion (PROMotion)" supported by the *European Commission*

### National

**2012–2015** Research Project "I-Mule", within the *Industry 2015 (Made in Italy)* program supported by the *Ministry of Economic Development*

**2008–2010** Coordinator of the National Research Project "SICURA: Safe Physical Interaction between Robots and Humans" supported by the *Ministry of Education University and Research*

**2003–2004** National Research Project "MATRICS: Methodologies Applications and Technologies for Robot Interaction Cooperation and Supervision" supported by the *Ministry of Education University and Research*

**2001–2003** Research Line "FAI ROBOT: Internet-based Continuous Learning for Industrial Robotic Systems Control" of the Project "Web Learning for Human Resources Quality" supported by the *National Research Council*

**2001–2002** National Research Project "MISTRAL: Methodologies and Integration of Subsystems and Technologies for Anthropic Robotics and Locomotion supported by the *Ministry of Education University and Research*

**1999–2000** National Research Project "RAMSETE: Articulated and Mobile Robotics for SErvice and TEchnology supported by the *Ministry of University, Scientific Research and Technology*

**1998–1999** Fundamental Research Project "Development of an Integrated Mobile Manipulator for Planetary Exploration Tasks" supported by the *Italian Space Agency*

**1997–1998** Special Research Project "Advanced Control for Robots with Flexible Elements: Theory and Experimentation" supported by the *National Research Council*

**1995–1996** Research Project "Motion Planning and Control of Mobile Robots" supported by the *Ministry of University, Scientific Research and Technology*

**1993–1994** Research Project "Control of Robots with Nonholonomic Constraints" supported by the *Ministry of University, Scientific Research and Technology*

**1989–1992** Research Line "Algorithms, Software, and Devices for Dynamic and Hybrid Control of Industrial Robots" of the Subproject "Robot Control" of the National Robotics Project supported by the *National Research Council*

# Society Service

**2012–2013** Vice-President for Publication Activities of the *IEEE Robotics and Automation Society (RAS)*

**2010–2011** Associate Vice-President for Publication Activities of the *IEEE Robotics and Automation Society (RAS)*

**2009–pres.** Chair of Panel PE-7 (Systems and Communication Engineering) of the *European Research Council (ERC)* for the Advanced Grant evaluation

**2008–2010** AdCom Member of the *IEEE Robotics and Automation Society (RAS)*

**from 2007** Fellow of the *IEEE (The Institute of Electrical and Electronics Engineers)* for contributions to modeling and control of robotic systems. Previously: Senior Member (2005), Member (1986), and Student Member (1982)

**from 2006** Member of the Search Committee for Physical Sciences (Technical Sciences until 2010) of the *Körber European Science Award*, granted by the Körber Foundation

**2001–2003** AdCom Member of the *European Robotics Research Network (EURON)*

**1998–1999** Member of SIRI (Società Italiana di Robotica Industriale)

**1991–1995** Chair of the *Technical Committee on Flexible Manipulators* in the *IEEE Robotics and Automation Society*

# Editorial Service

## Journals

**2004–2008** *Editor-in-Chief* of the *IEEE Transactions on Robotics*

**2003–2004** *Editor-in-Chief* of the *IEEE Transactions on Robotics and Automation*

**1998–2003** *Editor* of the *IEEE Transactions on Robotics and Automation* (first Editor not from USA)

**1994–1998** *Associate Editor* of the *IEEE Transactions on Robotics and Automation*

**1984–pres.** Reviewer for main archival journals in the areas of Robotics and Automatic Control, including *ASME Journal of Dynamic Systems, Measurements, and Control; Automatica; IEEE Transactions on Automatic Control; IEEE Transactions on Control Systems Technology; IEEE Transactions on Systems, Man, and Cybernetics; International Journal of Robotics Research; Journal of Robotics Systems*

## Handbook

**2008** One of the 165 selected authors of the *Springer Handbook of Robotics*, with a chapter on "Robots with Flexible Elements" (co-authored with W. Book, see [BC-12] in the list of publications)

## Main Conferences

**May 2013** Vice Co-Chair of *2013 IEEE International Conference on Robotics and Automation*, Karlsruhe, Germany

**Dec. 2012** Member of the International Advisory Committee of *12th International Conference on Control, Automation, Robotics and Vision*, Guangzhou, China

**Sep. 2011** CEB Editor of *2011 IEEE/RSJ International Conference on Intelligent Robots and Systems*, San Francisco, CA

**Sep. 2011** Publication Chair of *2011 IEEE/RSJ International Conference on Intelligent Robots and Systems*, San Francisco, CA

**Sep. 2011** Program Chair of *AUTOMATICA.IT 2011*, Pisa, Italy

**May 2011** RAS CEB Associate Editor of *2011 IEEE International Conference on Robotics and Automation*, Shanghai, PRC (three-year appointment)

**Dec. 2010** Member of the International Advisory Committee of *11th International Conference on Control, Automation, Robotics and Vision*, Singapore

**Oct. 2010** PC Member of *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Taipei, Taiwan

**May 2010** Member of the Senior Program Committee (SPC) of *2010 IEEE International Conference on Robotics and Automation*, Anchorage, AK

**Oct. 2009** PC Member of *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*, St. Louis, MO

**Dec. 2008** Member of the International Advisory Committee of *10th International Conference on Control, Automation, Robotics and Vision*, Hanoi, Vietnam

**Sep. 2008** European PC Member of *2008 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Nice, France

**Apr. 2007** General Chair of *2007 IEEE International Conference on Robotics and Automation*, Roma, Italy

**Dec. 2006** Member of the International Advisory Committee of *9th International Conference on Control, Automation, Robotics and Vision*, Singapore

**Oct. 2006** European PC Member of *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Beijing, China

**Sep. 2006** PC Member of *8th IFAC Symposium on Robot Control*, Bologna, Italy

**May 2006** IPC Member of *2006 IEEE International Conference on Robotics and Automation*, Orlando, FL

**Aug. 2005** European PC Member of *2005 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Edmonton, Canada

**Sep. 2004** European PC Member of *2004 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Sendai, Japan

**Apr. 2004** IPC Member of *2004 IEEE International Conference on Robotics and Automation*, New Orleans, LA

**Oct. 2003** European PC Member of *2003 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Las Vegas, NV

**Sep. 2003** IPC Member of *2003 IEEE International Conference on Robotics and Automation*, Taipei, Taiwan

**Sep. 2002** European PC Member of *2002 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Lausanne, Switzerland

**May 2002** IPC Member of *2002 IEEE International Conference on Robotics and Automation*, Washington, DC

**May 2001** IPC Member of *2001 IEEE International Conference on Robotics and Automation*, Seoul, Korea

**Apr. 2000** IPC Member of *2000 IEEE International Conference on Robotics and Automation*, San Francisco, CA

**May 1999** IPC Member of *1999 IEEE International Conference on Robotics and Automation*, Detroit, MI

**May 1998** IPC Member of *1998 IEEE International Conference on Robotics and Automation*, Leuven, Belgium

**Sep. 1995** Organizing Committee of *3rd European Control Conference*, Roma, Italy

**Dec. 1994** IPC Member of *33rd IEEE Conference on Decision and Control*, Lake Buenavista, FL

**Sep. 1994** Organizing Committee of *4th IFAC Symposium on Robot Control*, Capri, Italy

**Jun. 1989** Organizing Committee of *1st IFAC Symposium on Nonlinear Control Systems Design*, Capri, Italy

# Awards

**Apr. 2009** *IEEE-RAS Distinguished Service Award* for outstanding leadership and contributions as Editor-in-Chief of the IEEE Transactions on Robotics, and for service as the ICRA 2007 General Chair

**Mar. 2009** Supervisor of Paolo Robuffo Giordano, whose Ph.D. thesis received the *Premio Maffezzoni* for the best Italian thesis in the area of Systems and Control (Automatica) in 2008

**Feb. 2009** Chapter author of the *Springer Handbook of Robotics* that received the two *PROSE Awards* for Excellence in Physical Sciences & Mathematics and for Engineering & Technology, The American Publishers Awards for Professional and Scholarly Excellence

**Sep. 2008** *Best Application Paper Award* at the *2008 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Nice, France (see [C-105] in the list of publications)

**Apr. 2005** Recipient of the German *Helmholtz Humboldt Research Award* for foreign scientists

**Dec. 2003** Advisor of Giulio Milighetti, whose Laurea thesis received the *UCIMU National Award* for the best thesis in the section "Machines, Tools, and Components: Design and Applications", Milano, Italy

**May 1998** *Best Conference Paper Award* at the *1998 IEEE International Conference on Robotics and Automation*, Leuven, Belgium (see [C-59] in the list of publications)

**Jun. 1991** Coauthor with Costanzo Manes of the paper that received the *Best Student Paper Award* at the *5th International Conference on Advanced Robotics*, Pisa, Italy (see [C-33] in the list of publications)

**Jun. 1987** Technological innovation and transfer to the productive system award of the *Consorzio Roma Ricerche*

**Feb. 1984** University award for the best Master thesis "A new method for the optimization of interconnected systems" (see also [J-1] in the list of publications)

# Main Invited Seminars

**Jun. 2011** "Robots Collision Detection and Safe Reaction", *Centro "E. Piaggio*, Pisa, Italy

**Jan. 2011** "Control Issues for Safety and Performance in Robots with Flexible Transmissions", *Italian Institute of Technology*, Genova, Italy

**May 2010** "Dynamic Gravity Cancellation in Robots with Flexible Transmissions: Constant, Nonlinear, and Variable Stiffness", *Workshop on New Variable Impedance Actuators for the Next Generation of Robots*, 2010 IEEE International Conference on Robotics and Automation, Anchorage, Alaska

**Feb. 2006** "A Physically-Based Fault Detection and Isolation Method and Its Uses in Robot Manipulators", *38. VDI/VDE Sitzung des FA 4.13 Steuerung und Regelung von Robotern*, Ladenburg, Germany

**Jun. 2004** "On the Control of Robots with Visco-Elastic Joints", *Workshop on Applications of Advanced Control Theory to Robotics and Automation* (in honor of Proff. P. Kokotovic and S. Nicosia 70th Birthdays), Villa Mondragone, Roma, Italy

**Nov. 1999** "The Role of Advanced Control Systems in Service Robotics", *1st EU-JPN Symposium on Human Friendly Robotics*, Tokyo, Japan

**Jul. 1999** "Research Activities on Mobile Robotics at DIS", *LAAS–CNRS*, Toulouse, France

**May 1998** "Research Activities at DIS Robotics Laboratory", *Fraunhofer IPA*, Stuttgart, Germany

**Apr. 1998** "The Future of Robotics", *FAST Workshop on Automation Beyond Year 2000*, Milano, Italy

**Dec. 1997** "Trajectory Control of Flexible Manipulators", *IEEE CSS/RAS Workshop on Control Problems in Robotics and Automation: Future Directions*, San Diego, CA

**Jun. 1994** "Nonholonomic Behaviour in Redundant Robot Arms", *MAP Project on Geometry and Robotics*, Department of Mathematics, University of Pisa, Italy

**Dec. 1993** "An Iterative Learning Scheme for Regulation in Robot Arms", *École Polytechnique Fédéral de Lausanne*, Institut d'Automatique, Lausanne, Switzerland

**May 1992** "Control of Robots with Elastic Joints and Flexible Links", *Workshop on Control Issues to Promote Robotic Machine Intelligence*, 1992 IEEE International Conference on Robotics and Automation, Nice, France

# Significant Research Contributions

References are to papers in the separate list of publications (J = Journal paper, C = Conference paper, BC = Book chapter).

## Nonlinear Control

Theoretical contributions were provided for the problem of exact linearization of nonlinear systems via dynamic state feedback (see [C-6]) and the associated zero dynamics interpretation ([C-30]). Applications to different nonlinear electromechanical systems have been successfully considered, including induction motors ([J-5, C-13, C-18]), robots with various (joint, link) flexible components ([J-22, C-59, C-71, C-99, C-109]), nonholonomic wheeled mobile robots ([J-26, C-66]), and manipulators with passive joints ([J-25, J-28]).

## Flexible Manipulators

**Joint flexibility**— For robots with rigid links but flexible transmissions (harmonic drives, long shafts, or transmission belts), a complete and efficient exact linearization and decoupling algorithm by dynamic feedback has been developed. This result mimics the 'computed torque' approach of the rigid robot case and is useful for accurate trajectory tracking problems. It has been extended also to the case of a mixed rigid/elastic joint setting. Global results have been proven for the regulation of a desired configuration (or of a cartesian pose), based only on linear feedback of motor measurements and on-line gravity compensation (and the use of kinematic mappings for the cartesian case). Exact cancellation of the gravity acting on the robot links can be achieved for robots with linear, nonlinear or variable (actuated) stiffness, so that global regulation by a PD-type law follows without any lower bound on the control gains nor on the device stiffness. The case of visco-elastic joints has been considered, comparing the behavior of static versus dynamic feedback laws for input-output linearization. A simple method has been developed for the feasible dynamic scaling of trajectories under maximum torque constraints. A full state observer based on link acceleration and motor position measurements has been also proposed, and its use for control purposes validated on a KUKA robot with non-negligible joint elasticity. A novel (motor) friction observer and compensation has been introduced and tested on a 7R medical robot. A survey on the state-of-the-art on modeling and control of robots with elastic joints is given in a chapter of the *Springer Handbook of Robotics*. The case of variable stiffness actuation (VSA) has been also considered. Simultaneous decoupled control of link motion and joint stiffness can be obtained by feedback linearization methods. The problem of estimating on-line the time-varying nonlinear stiffness of VSA-based robots has been approached using a residual-based observer for the flexibility torques and an RLS scheme for obtaining the stiffness characteristics in real time. Both antagonistic and serial configurations of VSA have been covered, with experimental validation of the approach on the AwAS device of the IIT. For reference, see, e.g., [J-22, J-30, J-31, BC-12, C-11, C-59, C-64, C-73, C-79, C-84, C-86, C-93, C-96, C-106, C-109, C-112, C-113, C-114, C-115, C-118].

**Link flexibility**— A finite-dimensional closed-form dynamic modeling of open kinematic chain manipulators with flexible links has been proposed. Global regulation by PD control with constant or on-line gravity compensation has been shown for the first time

in the flexible case. An iterative update of the feedforward term can be used to make this controller fully independent of any dynamic parameter and also to achieve exact positioning of the deflected arm tip. Stable inversion control has been proposed for the accurate tracking of trajectories defined at special points along the links (in particular, at the link base, i.e., at the joint level). To cope with non-minimum phase limitations, nonlinear regulation is a viable solution to the problem of asymptotic tracking of end-effector trajectories, without the need to resort to non-causal torque commands. The problem of planning rest-to-rest motions in given time (without final oscillations) has been considered for a one-link and a two-link flexible arm. For reference, see, e.g., [J-3, J-4, J-8, J-11, J-12, J-15, J-17, J-29, BC-8, BC-10, BC-12, C-12, C-26, C-60, C-70, C-71, C-80, C-97, C-103].

## Kinematic Redundancy

Algorithms were proposed for the optimal use of kinematic redundancy, in order to maximize criteria like manipulability or joint range while moving the end-effector along a prescribed trajectory. The novel use of the compact and efficient Reduced Gradient method, the correct definition of second-order (acceleration) schemes, and the characterization and control of cyclic behaviors were the main contributions. The case of mobile manipulators with a nonholonomic wheeled base (NMM) that are redundant with respect to the task has been also considered, in particular for visual tasks. Notably, for the special case of NMM with steering wheels in the base, task-oriented kinematic control laws involve the use of dynamic feedback. Redundancy has been exploited also for a better Cartesian task preservation during the safe robot reaction to on-line detected collisions and for a more natural gaze control of a humanoid head. For reference, see, e.g., [J-7, J-10, J-18, J-20, J-34, C-24, C-40, C-65, C-90, C-104, C-110, C-117].

## Iterative Learning

When the robotic task is repetitive, one can use the previous trials for improving performance in the subsequent ones, without the need of an accurate dynamic model. The frequency-based design of an iterative learning controller for trajectory tracking tasks has been originally proposed, pointing out the trade-off between convergence of the learning process and asymptotic zeroing of the tracking error. The method has been applied to rigid, joint-elastic, as well as link-flexible robots. Learning can be used also for exploiting redundancy. For reference, see, e.g., [J-9, J-13, C-32, C-39].

## Hybrid Force/Velocity Control

We have proposed one of the first implementations of model-based hybrid force/velocity control. The correct complementarity of force and velocity vectors in the task space has been defined in energetic (thus, invariant) terms and extended also to the case of interaction with dynamic environments. In this latter case, three subsets of generalized

directions appear: those where only force can be controlled, those were only motion can be controlled, and those were either force or motion can be controlled, dynamically inducing the behavior of the other. Such hybrid force/velocity control framework naturally applies also to the case of multiple dynamically cooperating robots. For reference, see, e.g., [J-16, BC-4, C-15, C-20, C-33, C-36, C-47, C-50, C-55, C-56].

## Wheeled Mobile Robots

For the parking and trajectory tracking problems of wheeled mobile robots subject to nonholonomic constraints due to wheel rolling, full comparison of different advanced control laws has been performed in simulation and experimentally (time-varying nonlinear stabilization, non-smooth control, Lyapunov design in polar coordinates, dynamic feedback linearization). Both proprioceptive feedback (from odometry) and visual feedback (from an external camera) implementations were tested. Visual feedback has been used also for planning and execution of collision-free maneuvers among obstacles, keeping already into account the nonholonomic constraints. Adaptations to nonholonomic kinematics of artificial potential and vortex field methods have been also considered for sensor-based navigation of mobile robots. For reference, see, e.g., [J-14, J-26, BC-7, BC-9, C-45, C-53, C-62, C-75, C-76].

## Underactuated Robots

Underactuated robots have less control commands than generalized coordinates and display very difficult dynamic stabilization issues. Structural nonlinear controllability properties have been studied. For special classes of planar robots with one or more passive joints, a rest-to-rest motion planning technique and a trajectory tracking controller have been proposed using the flatness of the system (equivalently, its dynamic feedback linearizability). For the regulation to an equilibrium configuration (with or without gravity), a novel control method called iterative steering has been introduced. It consists in the sequential application of open-loop finite time commands leading to contraction of the state error. The open-loop command is evaluated at the state reached at the previous iteration, typically based on an approximate robot model (a polynomial nilpotent approximation which preserves the original system controllability and allows closed-form computations). Exponential convergence and robustness can be guaranteed under suitable hypotheses. This 'maneuvering' approach is valid also for minimalistic systems of robotic manipulation (plate-ball). For reference, see, e.g., [J-19, J-21, J-23, J-24, J-25, J-27, J-28, BC-11, C-61, C-68, C-74].

## Mobile Platforms

Within the project *CyberWalk*, an actuated ball-array platform has been built in order to allow unconstrained walking capabilities to a user immersed in a virtual reality. The platform has two actuators, one for a linear treadmill and one for the turntable supporting

it and its kinematic model is subject to a nonholonomic constraint. The motion control problem of this platform has been tackled, assuming to measure only the walker position with an overhead camera. The objective is to keep the walking user close to the platform center, using smooth (in terms of physiological perception constraints) control laws. The same control problem has been tackled for a 1D linear and a 2D omnidirectional treadmill, keeping into account the perceptual constraints of the walking user and integrating the system into a virtual reality visualizer. For the 2D omnidirectional treadmill, a more comfortable behavior is guaranteed by designing the two motion controllers in a reference frame attached to and rotated with the user. More recently, a large test campaign on users' behavior and possible changes in their locomotion on this large 2D platform has been performed. Another type of platforms where the presence of nonholonomic constraints is relevant are mobile manipulators mounted on a wheeled base. A task-oriented kinematic modeling allows to define a suitable Jacobian for these systems, to be used for kinematic control. The special case of visual tasks with an eye-in-hand camera has been considered. For reference, see, e.g., [J-34, J-37, J-38, C-90, C-91, C-92, C-94, C-108].

## Visual Servoing

Novel image-based control laws have been designed and tested on different experimental platform. They are based on a nonlinear observer for the depths of point features or for other geometric quantities associated to image moments, so as to realize a pure image-based visual servoing scheme. The same approach allows also an on-line estimation of the camera focal length. As applications, the kinematic control of mobile manipulators using on-board vision and the gazing control of the humanoid head of the ARMAR-III have been considered. For reference, see, e.g., [J-34, J-36, C-95, C-98, C-101, C-117].

## Fault Detection and Isolation

Theoretical and experimental results have been obtained on the problem of fault detection and isolation (FDI) in nonlinear dynamical systems. The proposed methods are based on a differential-geometric approach (for FDI of set of faults, when each single fault cannot be exactly isolated) and on the use of some inherent physical properties of the system (like conservation of momentum in Euler-Lagrange mechanical systems). The design of residual signals detecting and isolating actuator and/or sensor faults has been performed and tested in robotic systems as well as in hydraulic systems, in the face of modeling errors and measurement disturbances. For reference, see, e.g., [J-32, J-33, C-78, C-81, C-82, C-87, C-88, C-89].

## Physical Human-Robot Interaction

Within the project *PHRIENDS*, physical issues in human-robot interaction are studied. A robot collision detection scheme that does not use any external sensors beyond the proprioceptive ones (joint encoders, and joint torque sensors if available) has been developed

for rigid manipulators and for those having transmission elasticities, viewing the collision as a system fault. The associated residual can be computed efficiently, using also a modified Newton-Euler recursive algorithm. Experimental results have been obtained on the DLR-III lightweight arm, including also a safe reaction strategy to impacts with humans at any point of the robot structure. Tests have been conducted also for collision detection and reaction with sharp tools on biological tissues. For increasing robot safety while preserving motion accuracy, variable compliance joints/actuation has been considered. For this class of robots, we have shown the possibility of simultaneous and decoupled control of link motion and joint elasticity. Furthermore, collisions can be detected also without the knowledge of the actual joint stiffness. This subject of pHRI will be further pursued in the *SAPHARI* project, where in particular an integrated approach to collision avoidance, detection, and reaction will be pursued that integrates multiple exteroceptive and proprioceptive sensors, as well as dynamic model-based techniques. Preliminary results have been obtained for the collision avoidance using a Kinect sensor. Another issue that we will explore is the discrimination of undesired vs. intentional contacts and the safe control of continuous force exchange tasks in the latter case. For reference, see, e.g., [J-35, C-85, C-93, C-99, C-102, C-104, C-105, C-107, C-109, C-116].