Editors

Prof. Bruno Siciliano
Dipartimento di Ingegneria Elettrica
e Tecnologie dell’Informazione
Università degli Studi di Napoli
Federico II
Via Claudio 21, 80125 Napoli
Italy
E-mail: siciliano@unina.it

Prof. Oussama Khatib
Artificial Intelligence Laboratory
Department of Computer Science
Stanford University
Stanford, CA 94305-9010
USA
E-mail: khatib@cs.stanford.edu
Editorial Advisory Board

Oliver Brock, TU Berlin, Germany
Herman Bruyninckx, KU Leuven, Belgium
Raja Chatila, ISIR—UPMC & CNRS, France
Henrik Christensen, Georgia Tech, USA
Peter Corke, Queensland University of Technology, Australia
Paolo Dario, Scuola S. Anna Pisa, Italy
Rüdiger Dillmann, University of Karlsruhe, Germany
Ken Goldberg, UC Berkeley, USA
John Hollerbach, University of Utah, USA
Makoto Kaneko, Osaka University, Japan
Lydia Kavraki, Rice University, USA
Vijay Kumar, University of Pennsylvania, USA
Sukhan Lee, Sungkyunkwan University, Korea
Frank Park, Seoul National University, Korea
Tim Salcudean, University of British Columbia, Canada
Roland Siegwart, ETH Zurich, Switzerland
Gaurav Sukhatme, University of Southern California, USA
Sebastian Thrun, Stanford University, USA
Yangsheng Xu, The Chinese University of Hong Kong, PRC
Shin’ichi Yuta, Tsukuba University, Japan

More information about this series at http://www.springer.com/series/5208
Field and Service Robotics

Results of the 10th International Conference
Robotics is undergoing a major transformation in scope and dimension. From a largely dominant industrial focus, robotics is rapidly expanding into human environments and is vigorously engaged in its new challenges. Interacting with, assisting, serving, and exploring with humans, the emerging robots will increasingly touch people and their lives.

Beyond its impact on physical robots, the body of knowledge robotics has produced is revealing a much wider range of applications reaching across diverse research areas and scientific disciplines, such as biomechanics, haptics, neurosciences, virtual simulation, animation, surgery, and sensor networks among others. In return, the challenges of the new emerging areas are proving an abundant source of stimulation and insights for the field of robotics. It is indeed at the intersection of disciplines that the most striking advances happen.

The *Springer Tracts in Advanced Robotics* (STAR) is devoted to bringing to the research community the latest advances in the robotics field on the basis of their significance and quality. Through a wide and timely dissemination of critical research developments in robotics, our objective with this series is to promote more exchanges and collaborations among the researchers in the community and contribute to further advancements in this rapidly growing field.

The tenth edition of *Field and Service Robotics* edited by David S. Wettergreen and Timothy D. Barfoot offers in its eight-part volume a collection of a broad range of topics ranging from fundamental concepts such as control, vision, mapping, and recognition to advanced applications such as aquatic, planetary, aerial, and underground robots. The contents of the forty-two contributions represent a cross-section of the current state of robotics research from one particular aspect: field and service applications, and how they reflect on the theoretical basis of subsequent developments. Pursuing technologies aimed at non-factory robots that operate in complex and dynamic environments, as well as at service robots that work closely with humans to help them with their lives, is the big challenge running throughout this focused collection.
Rich in topics and authoritative contributors, FSR culminates with this unique reference on the current developments and new directions in field and service robotics. A fine addition to the series!

Naples, Italy
October 2015

Bruno Siciliano
STAR Editor
Field and Service Robotics (FSR) is the leading single-track conference on applications of robotics in challenging environments. Its goal is to report and encourage the development and experimental evaluation of field and service robots, and to generate a vibrant exchange and discussion in the community. Field robots are non-factory robots, typically mobile, that operate in complex and dynamic environments: on the ground (Earth or other planets), under the ground, underwater, in the air, or in space. Service robots are those that work closely with humans to help them with their lives.

The first FSR was held in Canberra, Australia, in 1997. Since that first meeting, FSR has been held roughly every two years, cycling through Asia, the Americas, and Europe. This book presents the results of the 10th edition of Field and Service Robotics, FSR 2015, held in Toronto, Canada, from 23 to 26 June 2015. This was the first time it has been held in Canada. This year we had 63 submitted papers from which we accepted 27 for oral presentations and 15 for poster presentations.

FSR 2015 was organized by the following team:

Timothy D. Barfoot
General Chair
University of Toronto

David S. Wettergreen
Program Chair
Carnegie Mellon University

Jonathan Kelly
Local Arrangements Chair
University of Toronto

Francois Pomerleau
Website and Publicity Chair
University of Toronto
Angela Schoellig  
Technical Tour Chair  
University of Toronto

The FSR 2015 International Program Committee generously provided their time to carry out detailed reviews of all the papers:

Peter Corke: Queensland University of Technology, Australia
Jonathan Roberts: Queensland University of Technology, Australia
Alex Zelinsky: DSTO, Australia
Uwe Zimmer: Australian National University, Australia
Salah Sukkarieh: University of Sydney, Australia
Ben Upcroft: Queensland University of Technology, Australia
Timothy D. Barfoot: University of Toronto, Canada
Jonathan Kelly: University of Toronto, Canada
David S. Wettergreen: Carnegie Mellon University, USA
Philippe Giguere: University of Laval, Canada
Steve Waslander: University of Waterloo, Canada
Josh Marshall: Queens University, Canada
Francois Pomerleau: University of Toronto, Canada
Chris Skonieczny: Concordia University, Canada
Arto Visala: Helsinki University of Technology, Finland
Simon Lacroix: LAAS, France
Christian Laugier: INRIA, France
Cedric Pradalier: GT-Lorraine, France
Andreas Birk: Jacobs University, Germany
Keiji Nagatani: Tohoku University, Japan
Kazuya Yoshida: Tohoku University, Japan
Takashi Tsubouchi: University of Tsukuba, Japan
Genya Ishigami: Keio University, Japan
Miguel Angel Salichs: Universidad Carlos III de Madrid, Spain
Roland Siegwart: ETH Zurich, Switzerland
David P. Miller: University Oklahoma, USA
Sanjiv Singh: Carnegie Mellon University, USA
Gaurav Sukhatme: University of Southern California, USA
Alonzo Kelly: Carnegie Mellon University, USA
Chuck Thorpe: Clarkson University, USA
David Silver: Google[X], USA
Carrick Dettweiler: University of Nebraska, USA
Stewart Moorehead: John Deere Corp., USA
Steve Nuske: Carnegie Mellon University, USA
Gabe Sibley: University of Colorado, USA
Ross Knepper: Cornell University, USA
Michael Jakuba: Woods Hole, USA
In addition to the submitted papers presented at the conference, there were four excellent keynote speakers at FSR 2015 and we would like to acknowledge their excellent contributions to the conference:

- Chris Urmson, Director, Self-Driving Cars, Google, “Realizing Self-Driving Vehicles”
- Paul Newman, Professor, University of Oxford, “Fielding Robots with Learnt Place-Specific Excellence”
- Sanjiv Singh, Professor, Carnegie Mellon University, “As the Drone Flies: The Shortest Path from Ground to Aerial Autonomy”
- Ryan Gariepy, Chief Technology Officer, Clearpath Robotics, “The Evolution of a Robotics Company”

FSR 2015 would not have been possible without the generous support of our sponsors. In particular, Clearpath Robotics went above and beyond to provide financial and in-kind support. The University of Toronto Institute for Aerospace Studies and Faculty of Applied Science and Engineering also provided financial support.

David S. Wettergreen
Timothy D. Barfoot
Contents

Part I Aquatic

A Spatially and Temporally Scalable Approach for Long-Term Lakeshore Monitoring ........................................... 3
Shane Griffith and Cédric Pradalier

Autonomous Greenhouse Gas Sampling Using Multiple Robotic Boats .......................................................... 17
Matthew Dunbabin

Experimental Analysis of Receding Horizon Planning Algorithms for Marine Monitoring ........................................ 31
Soo-Hyun Yoo, Andrew Stuntz, Yawei Zhang, Robert Rothschild, Geoffrey A. Hollinger and Ryan N. Smith

Return to Antikythera: Multi-session SLAM Based AUV Mapping of a First Century B.C. Wreck Site .................. 45
Stefan B. Williams, Oscar Pizarro and Brendan Foley

An Overview of MIT-Olin’s Approach in the AUVSI RobotX Competition ......................................................... 61
Arthur Anderson, Erin Fischell, Thom Howe, Tom Miller, Arturo Parrales-Salinas, Nick Rypkema, David Barrett, Michael Benjamin, Alex Brennen, Michael DeFillipo, John J. Leonard, Liam Paull, Henrik Schmidt, Nick Wang and Alon Yaari

A Parameterized Geometric Magnetic Field Calibration Method for Vehicles with Moving Masses with Applications to Underwater Gliders .................................................. 81
Brian Claus and Ralf Bachmayer
Towards Autonomous Robotic Coral Reef Health
Assessment ................................................................. 95
Travis Manderson, Jimmy Li, David Cortés Poza, Natasha Dudek,
David Meger and Gregory Dudek

Part II Vision
BOR\(^2\)G: Building Optimal Regularised Reconstructions
with GPUs (in Cubes) ............................................ 111
Michael Tanner, Pedro Piniés, Lina Maria Paz and Paul Newman

Online Loop-Closure Detection via Dynamic Sparse Representation... 125
Moein Shakeri and Hong Zhang

Large Scale Dense Visual Inertial SLAM .......................... 141
Lu Ma, Juan M. Falquez, Steve McGuire and Gabe Sibley

Dense and Swift Mapping with Monocular Vision ................... 157
Pedro Piniés, Lina Maria Paz and Paul Newman

Wrong Today, Right Tomorrow: Experience-Based Classification
for Robot Perception .................................................. 173
Jeffrey Hawke, Corina Gurău, Chi Hay Tong and Ingmar Posner

Beyond a Shadow of a Doubt: Place Recognition with
Colour-Constant Images ............................................. 187
Kirk MacTavish, Michael Paton and Timothy D. Barfoot

Segmentation and Classification of 3D Urban Point Clouds:
Comparison and Combination of Two Approaches ................. 201
A.K. Aijazi, A. Serna, B. Marcotegui, P. Checchin and L. Trassoudaine

A Stereo Vision Based Obstacle Detection System
for Agricultural Applications ........................................ 217
Patrick Fleischmann and Karsten Berns

CoPilot: Autonomous Doorway Detection and Traversal
for Electric Powered Wheelchairs .................................. 233
Tom Panzarella, Dylan Schwesinger and John Spletzer

Learning a Context-Dependent Switching Strategy
for Robust Visual Odometry ......................................... 249
Kristen Holtz, Daniel Maturana and Sebastian Scherer

Part III Planetary
System Design of a Tethered Robotic Explorer (TReX)
for 3D Mapping of Steep Terrain and Harsh Environments ..... 267
Patrick McGarey, François Pomerleau and Timothy D. Barfoot
Design, Control, and Experimentation of Internally-Actuated Rovers for the Exploration of Low-Gravity Planetary Bodies .......... 283
B. Hockman, A. Frick, I.A.D. Nesnas and M. Pavone

Considering the Effects of Gravity When Developing and Field Testing Planetary Excavator Robots ............................................. 299
Krzysztof Skonieczny, Thomas Carlone, W.L. “Red” Whittaker and David S. Wettergreen

Update on the Qualification of the Hakuto Micro-rover for the Google Lunar X-Prize .............................................................. 313
John Walker, Nathan Britton, Kazuya Yoshida, Toshiro Shimizu, Louis-Jerome Burtz and Alperen Pala

Mobility Assessment of Wheeled Robots Operating on Soft Terrain .................................................................................. 331
Bahareh Ghotbi, Francisco González, József Kövecses and Jorge Angeles

Taming the North: Multi-camera Parallel Tracking and Mapping in Snow-Laden Environments ............................................. 345
Arun Das, Devinder Kumar, Abdelhamid El Bably and Steven L. Waslander

Four-Wheel Rover Performance Analysis at Lunar Analog Test ...... 361
Nathan Britton, John Walker, Kazuya Yoshida, Toshiro Shimizu, Tommaso Paniccia and Kei Nakata

Energy-Aware Terrain Analysis for Mobile Robot Exploration .... 373
Kyohei Otsu and Takashi Kubota

Part IV Aerial

Vision and Learning for Deliberative Monocular Cluttered Flight .... 391
Debadeepta Dey, Kumar Shaurya Shankar, Sam Zeng, Rupesh Mehta, M. Talha Agcayazi, Christopher Eriksen, Shreyansh Daftry, Martial Hebert and J. Andrew Bagnell

Robust Autonomous Flight in Constrained and Visually Degraded Environments ................................................................. 411
Zheng Fang, Shichao Yang, Sezal Jain, Geetesh Dubey, Silvio Maeta, Stephan Roth, Sebastian Scherer, Yu Zhang and Stephen Nuske

Autonomous Exploration for Infrastructure Modeling with a Micro Aerial Vehicle ......................................................... 427
Luke Yoder and Sebastian Scherer
Long-Endurance Sensing and Mapping Using a Hand-Launchable Solar-Powered UAV
Philipp Oettershagen, Thomas Stastny, Thomas Mantel, Amir Melzer, Konrad Rudin, Pascal Gohl, Gabriel Agamennoni, Kostas Alexis and Roland Siegwart

Aerial Vehicle Path Planning for Monitoring Wildfire Frontiers
Ryan C. Skeele and Geoffrey A. Hollinger

Part V Underground

Multi-robot Mapping of Lava Tubes
X. Huang, J. Yang, M. Storrie-Lombardi, G. Lyzenga and C.M. Clark

Admittance Control for Robotic Loading: Underground Field Trials with an LHD
Andrew A. Dobson, Joshua A. Marshall and Johan Larsson

From ImageNet to Mining: Adapting Visual Object Detection with Minimal Supervision
Alex Bewley and Ben Upcroft

Part VI Systems

Building, Curating, and Querying Large-Scale Data Repositories for Field Robotics Applications
Peter Nelson, Chris Linegar and Paul Newman

Search and Retrieval of Human Casualties in Outdoor Environments with Unmanned Ground Systems—System Overview and Lessons Learned from ELROB 2014
Bernd Brüggemann, Dennis Wildermuth and Frank E. Schneider

Monocular Visual Teach and Repeat Aided by Local Ground Planarity
Lee Clement, Jonathan Kelly and Timothy D. Barfoot

In the Dead of Winter: Challenging Vision-Based Path Following in Extreme Conditions
Michael Paton, François Pomerleau and Timothy D. Barfoot

Non-Field-of-View Acoustic Target Estimation in Complex Indoor Environment
Kuya Takami, Tomonari Furukawa, Makoto Kumon and Gamini Dissanayake
Novel Assistive Device for Teaching Crawling Skills to Infants ........ 593
Mustafa A. Ghazi, Michael D. Nash, Andrew H. Fagg, Lei Ding,
Thubi H.A. Kolobe and David P. Miller

SPENCER: A Socially Aware Service Robot for Passenger
Guidance and Help in Busy Airports ................................. 607
Rudolph Triebel, Kai Arras, Rachid Alami, Lucas Beyer,
Stefan Breuers, Raja Chatila, Mohamed Chetouani,
Daniel Cremers, Vanessa Evers, Michelangelo Fiore, Hayley Hung,
Omar A. Islas Ramirez, Michiel Joosse, Harmish Khambhaita,
Tomasz Kucner, Bastian Leibe, Achim J. Lilienthal, Timm Linder,
Manja Lohse, Martin Magnusson, Billy Okal, Luigi Palmieri,
Umer Rafi, Marieke van Rooij and Lu Zhang

Easy Estimation of Wheel Lift and Suspension Force for a Novel
High-Speed Robot on Rough Terrain ................................. 623
Jayoung Kim, Bongsoo Jeon and Jihong Lee

Application of Multi-Robot Systems to Disaster-Relief Scenarios
with Limited Communication ............................................. 639
Jason Gregory, Jonathan Fink, Ethan Stump, Jeffrey Twigg,
John Rogers, David Baran, Nicholas Fung and Stuart Young