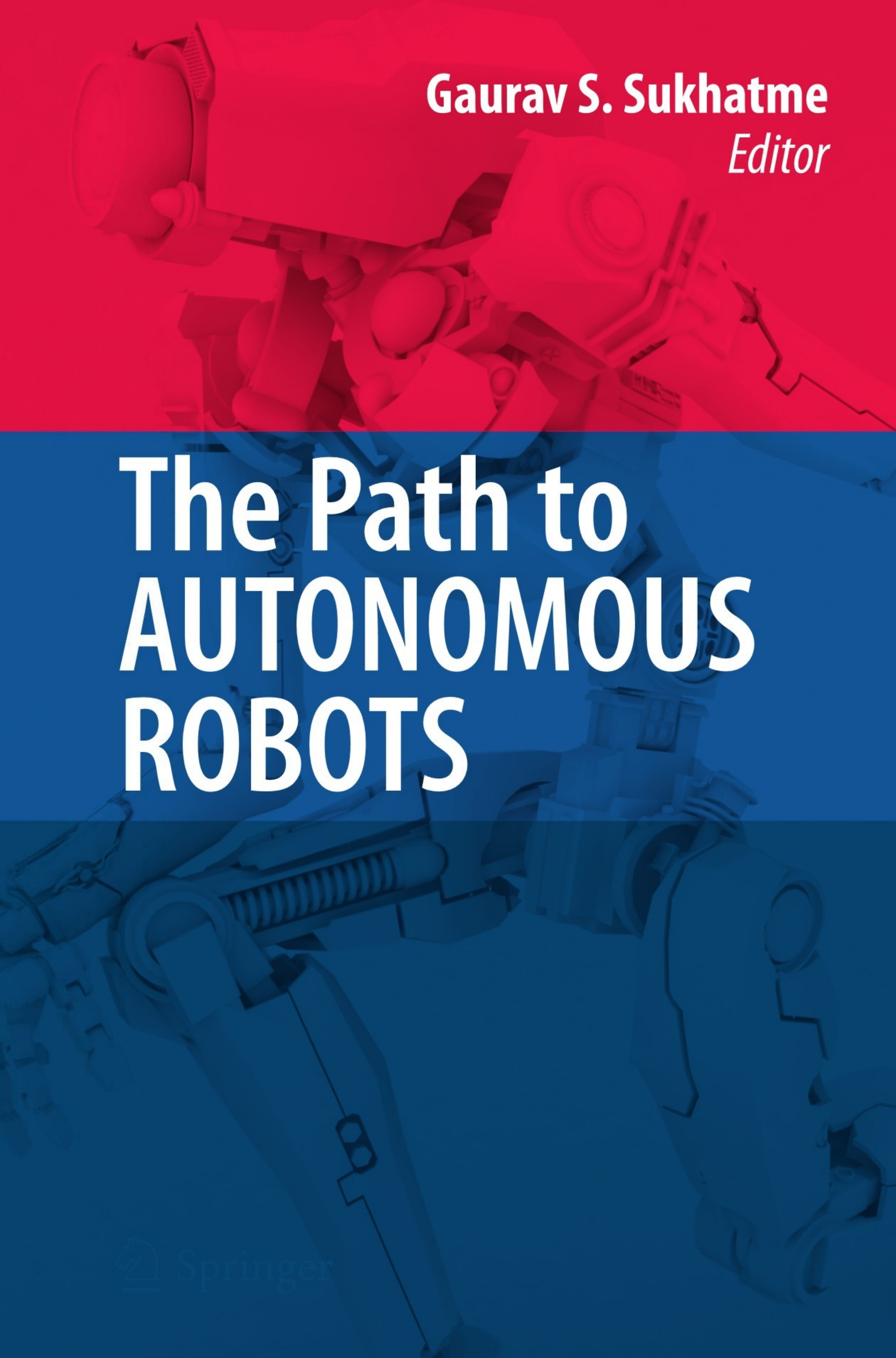

Gaurav S. Sukhatme
Editor

The Path to AUTONOMOUS ROBOTS

Springer

The Path to Autonomous Robots

Essays in Honor of George A. Bekey

The Path to Autonomous Robots

Essays in Honor of George A. Bekey

Edited by

Gaurav S. Sukhatme

Springer

Editor
Gaurav S. Sukhatme
Department of Computer Science
University of Southern California MC 2905
Ronald Tutor Hall (RTH 405)
3710 South McClintock Avenue
Los Angeles, California 90089-2905
gaurav@usc.edu

ISBN: 978-0-387-85773-2 e-ISBN: 978-0-387-85774-9
DOI: 10.1007/978-0-387-85774-9

Library of Congress Control Number: 2008934647

Printed on acid-free paper

springer.com

To Professor George A. Bekey, on the occasion of his 80^{th} birthday.

Preface

The principal chapters of this book form a collection of technical articles spanning many areas of research in robotics, these are followed by a set of short reminiscences and tributes written by former students of Professor George A. Bekey. Professor Bekey, a pioneer in robotics, retired from the University of Southern California (USC) in 2002 after serving on its faculty for forty years. He maintains an association with USC as University Professor Emeritus. Professor Bekey turned 80 in June 2008 - this is his Festschrift.

As one of Professor Bekey's former students, it has been my privilege to know him for many years. This book represents the collective warm feelings of his former students, who remember their association with him in the fondest terms.

Part I of this book is composed of technical chapters representing threads of active robotics research knitted loosely together. In many cases the themes of the chapters have their origins in the work the authors did when they were graduate students with Professor Bekey. These chapters are written for the reader interested in a sampling of modern research in Autonomous Robots. It is my hope that, for the serious reader, these chapters will serve as invitations to explore the field via further reading and research.

Part II of this book is composed of short, non-technical essays by former students of Professor Bekey. These serve to illustrate his multifaceted personality, and put on record the feelings of affection which many of us have for him.

Los Angeles
August 2008

Gaurav S. Sukhatme

Contents

List of Contributors

Arvin Agah
Electrical Engineering and Computer Science Department, University of Kansas, Lawrence, KS 66045, e-mail: agah@ku.edu

Eric L. Akers
Mathematics and Computer Science Department, Elizabeth City State University, Elizabeth City, NC 27909, e-mail: elakers@mail.ecsu.edu

Behcet Açıkmeşe
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, e-mail: Behcet.Acikmese@jpl.nasa.gov

Dan Antonelli
Biokinesiology and Physical Therapy, Biomedical Engineering (retd.), University of Southern California, Los Angeles, CA 90089, e-mail: dantonel@usc.edu

Arun Bhadoria
Manufacturing Engineering Leader, Cummins Emission Solutions, Mineral Point, WI 53565, e-mail: arun.bhadoria@cummins.com

Douglas Brooks
Human-Automation Systems (HumAnS) Lab, Center for Healthcare Robotics@Health Systems Institute, Georgia Institute of Technology, Atlanta, GA 30332, e-mail: bdouglas8@gatech.edu@ece.gatech.edu

Charles de Granville
Symbiotic Computing Laboratory, School of Computer Science, University of Oklahoma, Norman, OK 73019, e-mail: chazz184@gmail.com

Willis G. Downing, Jr.
Professor of Biomedical and Electrical Engineering Emeritus, College of Engineering and Computer Science, California State University, Northridge, CA 91330, e-mail: wgdowning@netptc.net

Andrew H. Fagg

Symbiotic Computing Laboratory, School of Computer Science, University of Oklahoma, Norman, OK 73019, e-mail: fagg@cs.ou.edu

Christopher M. Gifford
Electrical Engineering and Computer Science Department, University of Kansas, Lawrence, KS 66045, e-mail: cgifford@eecs.ku.edu

Fred Y. Hadaegh
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, e-mail: Fred.Y.Hadaegh@jpl.nasa.gov

Ayanna M. Howard
Human-Automation Systems (HumAnS) Lab, Center for Healthcare Robotics@Health Systems Institute, Georgia Institute of Technology, Atlanta, GA 30332, e-mail: ayanna@ece.gatech.edu

Gerard Jounghyun Kim
Digital Experience Laboratory, Korea University, e-mail: gjkim@korea.ac.kr

Theresa J. Klein
Department of Electrical and Computer Engineering, University of Arizona, Tucson, AZ, 85721, e-mail: tjk@ece.arizona.edu

M. Anthony Lewis
Department of Electrical and Computer Engineering, University of Arizona, Tucson, AZ, 85721, e-mail: malewis@ece.arizona.edu

Huan Liu
Department of Computer Science and Engineering, Arizona State University, Tempe AZ 85287-8809, e-mail: huanliu@asu.edu

Milan Mandić
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, e-mail: Milan.Mandic@jpl.nasa.gov

Michael Merritt
Mission Systems, Northrup Grumman Corporation, e-mail: michael.merritt@ngc.com

L. Warren Morrison
Founder and Chief Technology Officer, ITG LABS LLC, e-mail: warrenmster@gmail.com

Chung Hyuk Park
Human-Automation Systems (HumAnS) Lab, Center for Healthcare Robotics@Health Systems Institute, Georgia Institute of Technology, Atlanta, GA 30332, e-mail: chunghyuk@ece.gatech.edu

Hae Won Park
Human-Automation Systems (HumAnS) Lab, Center for Healthcare Robotics@Health Systems Institute, Georgia Institute of Technology,

Atlanta, GA 30332, e-mail: hindol21@ece.gatech.edu

Robert Platt, Jr.,
Dexterous Robotics Laboratory, Johnson Space Center, NASA, Houston, TX,
e-mail: robert.platt-1@nasa.gov

Sekou Remy
Human-Automation Systems (HumAnS) Lab, Center for Healthcare Robotics@Health Systems Institute, Georgia Institute of Technology,
Atlanta, GA 30332, e-mail: sekou@ece.gatech.edu

Daniel P. Scharf
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109,
e-mail: Daniel.P.Scharf@jpl.nasa.gov

H. Pete Schmid
Director, Advanced Technology (retd.), Raytheon Missile Systems Company,
Tucson, Arizona, e-mail: pete.schmid@alumni.usc.edu

Gurkirpal Singh
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109,
e-mail: Gurkipal.Singh@jpl.nasa.gov

Joshua Southerland
Symbiotic Computing Laboratory, School of Computer Science, University of Oklahoma, Norman, OK 73019,
e-mail: Joshua.B.Southerland-1@ou.edu

Richard S. Stansbury
Department of Computer and Software Engineering, Embry-Riddle Aeronautical University, Daytona Beach, FL 32114,
e-mail: richard.stansbury@erau.edu

Gaurav S. Sukhatme
Department of Computer Science, University of Southern California, Los Angeles,
CA 90089-0781, e-mail: gaurav@usc.edu

Monte Ung
Department of Electrical Engineering, University of Southern California, Los Angeles, CA 90089, e-mail: ung@ceng.usc.edu

Di Wang
Symbiotic Computing Laboratory, School of Computer Science, University of Oklahoma, Norman, OK 73019, e-mail: di@cs.ou.edu

Dit-Yan Yeung
Department of Computer Science and Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China,
e-mail: dyyeung@cse.ust.hk

Bin Zhang

Department of Computer Science, University of Southern California, Los Angeles, CA 90089-0781, e-mail: binz@usc.edu

Yu Zhang
Department of Computer Science and Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China,
e-mail: zhangyu@cse.ust.hk

Part I
Recent Research in Autonomous Robots

The eight chapters which make up this part of the book span separate research areas in Autonomous Robots. It has long been clear that robots will play a significant role in applications which are dirty, dull or dangerous. However many fundamental challenges remain to be addressed before robots become ubiquitous. The chapters in part I of this book address some of these challenges. Some chapters take a basic research perspective, and others take an application-driven viewpoint. In the first chapter, Agah and colleagues at the University of Kansas describe the design of mobile robots for seismic and radar remote sensing of ice sheets in polar regions - one of the most hostile environments on the planet. This is followed by an account of autonomous spacecraft from Hadaegh and colleagues at the Jet Propulsion Laboratory, another example of robots in extreme environments. In chapter three Sukhatme and Zhang at the University of Southern California describe the design of networked robotic systems with applications to sensing and sampling the aquatic environment. While the first three chapters deal largely with mobile robots (albeit with dramatically different kinds of mobility), clearly autonomy implies the ability not only to sense and move, but to manipulate the environment. In chapter four, Fagg and colleagues at Oklahoma University describe their recent research in robotic grasping using inputs from vision systems. Designers of autonomous systems cannot help but admire the plethora of natural autonomous systems in the world around us - living beings. In chapter five, Howard and colleagues at the Georgia Institute of Technology discuss advances in both manipulation and mobility which are inspired by human control systems. This is followed by a discussion by Kim on new directions in human-robot interaction. Lewis and Klein also take a biomimetic approach to autonomous robot design, and provide an introduction to neurobotics. A fundamental characteristic of living beings is that they learn. In this spirit, the eighth and final chapter by Yeung and Zhang investigates the feasibility of applying multi-task learning to the problem of inverse dynamics.

Chapter 1
Mobile Robots for Polar Remote Sensing

Christopher M. Gifford, Eric L. Akers, Richard S. Stansbury, and Arvin Agah

Abstract Mobile robots are becoming more heavily used in environments where human involvement is limited, impossible, or dangerous. These robots perform some of the more dangerous and laborious human tasks on Earth and throughout the solar system, many times with greater efficiency and accuracy, saving both time and resources. As we explore further away from Earth, higher levels of autonomy are also becoming more desired in such applications, one of them being remote sensing. This chapter covers mobile robots that have been designed and built at the University of Kansas to facilitate seismic and radar remote sensing of ice sheets in polar regions. These robots have been developed for and deployed in unstructured, polar environments. System designs, components, deployment and data acquisition algorithms, and experimental results are discussed. In this chapter, future applications, such as an autonomous multi-robot seismic surveying team, are simulated. Future planetary missions will hopefully incorporate similar robotic systems to conduct in-situ experiments on other planets.

Christopher M. Gifford
Electrical Engineering and Computer Science Department, University of Kansas, Lawrence, KS 66045, e-mail: `cgifford@eecs.ku.edu`

Eric L. Akers
Mathematics and Computer Science Department, Elizabeth City State University, Elizabeth City, NC 27909, e-mail: `elakers@mail.ecsu.edu`

Richard S. Stansbury
Department of Computer and Software Engineering, Embry-Riddle Aeronautical University, Daytona Beach, FL 32114, e-mail: `richard.stansbury@erau.edu`

Arvin Agah
Electrical Engineering and Computer Science Department, University of Kansas, Lawrence, KS 66045, e-mail: `agah@ku.edu`

1.1 Introduction

At the University of Kansas, the Center for Remote Sensing of Ice Sheets (CReSIS) (48) performs polar research to gather data and model ice sheets to better understand climate change and its effects on sea level rise. We have designed, built, and deployed mobile robots to autonomously traverse polar terrain and support experiments in Greenland and Antarctica. The problem we are faced with is to facilitate the use, and increase the efficiency of seismic and radar data acquisition in these types of environments. Integration of autonomy and mobility into remote sensing methods can potentially improve and enhance the process.

One of the sensors used to perform this research is a seismic sensor, or geophone. These highly sensitive geophones detect vibrations in the ground which can be recorded as images. These images, for example, can show characteristics of the subsurface, detect cracking (fault) locations, as well as provide information on what is beneath the ice sheets. CReSIS has also developed ground and ice penetrating radars that can also provide highly detailed images of the subsurface. We have used these radars to identify layers and areas of potential water within Earth's ice sheets, as well as the extent of water presence at the interface between the ice sheet and the underlying bedrock. Together, these remote sensing techniques allow us to study and further understand how polar regions are changing in response to climate change.

Research in the field of robotics has been focusing on accurate sensing and autonomy, mostly performed in structured environments such as factories and homes. Robotic applications involving remote sensing and in-situ experiments in unstructured environments have, however, been limited. Not only are navigation and actuation in such environments difficult problems, autonomy in hazardous environments represent larger challenges (166).

Another important aspect of integrating robotics and remote sensing surveys is that it limits human involvement, the most dangerous and costly portion of a survey. The accuracy and quality of acquired data can also be potentially increased. For polar and planetary environments, this becomes extremely important for safety, reliability, and resource consumption. Furthermore, robotics increases precision and introduces repeatability into an otherwise time-consuming and complex human task. In particular, because seismic deployment is labor-intensive, expensive in terms of time and cost, and possibly dangerous, autonomously performing such tasks using mobile robots can be highly beneficial. Therefore, the goal is to combine robotics research with remote sensing systems to autonomously image the subsurface for polar and planetary applications.

As we explore further away from Earth, a need for a coupled increase in intelligence and autonomy arises as a result of large communication delays between robots and their remote human operators. During communication delays, robots could navigate to new locations, perform experiments, or build a map of an unexplored region of the surface. Other planets and their moons offer various unique and challenging environments for ground-based robots, ranging from the extreme heat and pressure on the surface of Venus to the icy landscape of Jupiter's moon Europa. Future missions to the icy moon Europa may one day include a multi-robot seismic mission to