

Chapter 1

INTRODUCTION

Robotics is an extremely dynamic field with thriving advancement in its technology. Along with other emerging technologies such as information technology, biotechnology, and nanotechnology, robotics will contribute to increasing opportunities for economic growth and greatly affect future generations with substantial social and economic impacts.

To assess the status of robotics R&D in the world and to compare the US efforts with those of other countries in terms of quality, scope, and funding, an international study on the status of robotics was conducted during 2004–2005 with grants from the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA) and some additional funding from the National Institute of Biomedical Imaging and Bioengineering (NIBIB). This book presents the state of the art and future challenges in the major areas of robotics, based on the international study report from the World Technology Evaluation Center (WTEC, <http://wtec.org/robotics>).

Under the leadership of Junku Yuh (who was at the time the Director of the Robotics and Computer Vision Program at NSF), David Lavery from NASA Headquarters and Y. T. Chien, the Director of Research for WTEC, a study team was formed. The study team consisted of two NASA scientists and four university faculty members, representing a broad cross-section of experience in the robotics field. In alphabetical order, the team members were:

- Robert Ambrose, NASA Johnson Space Center
- George Bekey, University of Southern California (Chair)
- Vijay Kumar, University of Pennsylvania
- Arthur Sanderson, Rensselaer Polytechnic Institute
- Brian Wilcox, NASA Jet Propulsion Laboratory
- Yuan Zheng, Ohio State University

To assess the status of robotics R&D in the United States and to provide a baseline for comparisons with efforts in other countries, a workshop was held at NSF on 21–22 July 2004. This invitational workshop was attended by some 100 researchers from universities, research laboratories, government, and industry, who presented “Status Reports” in a number of areas of robotics, including technology areas such as actuators and mechanisms, robot control, intelligence and learning, human–robot interaction, multirobot systems, and humanoid robots, and applications in such fields as entertainment, education, medicine and rehabilitation, military, space, and underwater. The materials presented at the workshop are available at http://wtec.org/robotics/us_workshop. Following the workshop, it was decided to narrow the scope of the international study into the following six areas: robotic vehicles; space robotics; humanoid robots; industrial, service and personal robots; robotics in biology and medicine; and networked robots.

In October 2004, the team traveled to Japan and South Korea, visiting 29 laboratories. In April 2005, an additional 21 laboratories were visited in France, Germany, Italy, Spain, Sweden, Switzerland, and the United Kingdom. In addition, a “virtual site visit” to Australia was conducted through e-mail. While there are significant works in robotics in other countries (such as Belgium, China, Russia, and others) the itinerary was constrained by time and budget. Based on extensive discussions among team members, consultation with sponsors, and e-mail discussions with colleagues throughout the world, visits were restricted to the specific countries listed above. The complete list of all sites visited is given in Table 1.1.

Most visits were completed in half a day. Even so, in order to visit 20 laboratories in Japan in 1 week, it was necessary to split the team into two subgroups. The number of sites visited in Europe was so large that the team was divided into three subgroups. Fortunately, these smaller groups were augmented by the following representatives from NASA, NSF, and WTEC who participated in the visits and assisted significantly in the gathering of information: David Lavery, NASA Headquarters; Mino Dastoor; NASA Headquarters; Junku Yuh, NSF; Y. T. Chien, WTEC; Hassan Ali, WTEC; and Masanobu Miyahara, WTEC.

In order to focus the discussions in the various laboratories, the host engineers and scientists were provided with a set of questions prior to the visits. While the discussion did not necessarily follow the specific questions,

Table 1.1. Sites visited in Asia and Europe.

Site	Panelists	Date
Europe		
<i>France</i>		
Centre National d'Etudes Spatiales de Toulouse	Ambrose, Chien, Dastoor, Wilcox	25 April 2005
Cybernétix	Ali, Sanderson, Yuh, Zheng	27 April 2005
Institut Français de Recherché pour l'Exploitation de la Mer (IFREMER)	Ali, Sanderson, Yuh, Zheng	27 April 2005
Institut National de Recherche en Informatique et en Automatique (INRIA)	Ali, Sanderson, Yuh, Zheng	28 April 2005
Laboratoire d'Analyse et d'Architecture des Systèmes — Centre National de la Recherche Scientifique (LAAS/CNRS)	Ambrose, Chien, Dastoor, Lavery, Wilcox	26 April 2005
<i>Germany</i>		
Charite Hospital	Ambrose, Chien, Dastoor, Lavery, Wilcox	28 April 2005
DLR German Aerospace Center	Ambrose, Bekey, Chien, Kumar, Lavery, Wilcox	27 April 2005
Fraunhofer Institute — Production Systems and Design Technology (IPK)	Ambrose, Chien, Lavery, Wilcox	28 April 2005
Karlsruhe University	Bekey, Kumar	28 April 2005
Technical University Berlin	Ambrose, Chien, Dastoor, Lavery, Wilcox	28 April 2005
Technical University Munich	Ambrose, Bekey, Chien, Dastoor, Kumar, Lavery, Wilcox	27 April 2005
<i>Italy</i>		
Università di Genova	Ali, Yuh, Zheng	29 April 2005
Scuola Superiore Sant'Anna	Ali, Sanderson, Yuh, Zheng	29 April 2005
<i>Spain</i>		
Universitat de Girona	Sanderson, Yuh	22 April 2005
<i>Sweden</i>		
ABB Laboratory	Ambrose, Bekey, Chien, Kumar, Wilcox	29 April 2005
Kungl Teknisha Hogskolan (KTH)	Bekey, Kumar	28 April 2005
<i>Switzerland</i>		
École Polytechnique Fédérale de Lausanne (EPFL)	Bekey, Kumar	26 April 2005

Table 1.1. (Continued).

Site	Panelists	Date
Swiss Federal Institute of Technology (ETH)	Bekey, Kumar	25 April 2005
University of Zürich	Bekey, Kumar	25 April 2005
<i>United Kingdom</i>		
Heriot-Watt University	Ali, Sanderson, Yuh, Zheng	25 April 2005
Oxford University	Ali, Sanderson, Yuh, Zheng	26 April 2005
Asia		
<i>Japan</i>		
National Institute of Advanced Industrial Science and Technology (AIST)	Ambrose, Bekey, Lavery, Wilcox, Yuh, Zheng	6 Oct 2004
AIST — Intelligent Systems Research Institute	Ambrose, Chien, Wilcox	8 Oct 2004
ATR Computational Neuroscience Laboratories	Chien, Dastoor, Sanderson	5 Oct 2004
ATR Intelligent Robotics and Communication Laboratories	Chien, Dastoor, Sanderson	5 Oct 2004
FANUC	Chien, Kumar, Zheng	8 Oct 2004
Fujitsu Autonomous Systems Lab	Ambrose, Chien, Kumar, Lavery, Wilcox, Yuh	5 Oct 2004
Japan Agency for Marine Earth Science and Technology (JAMSTEC)	Chien, Kumar, Sanderson, Yuh, Zheng	4 Oct 2004
Keio University — Kawasaki Campus	Ambrose, Bekey, Kumar, Miyahara, Wilcox, Yuh, Zheng	5 Oct 2004
Keio University — Shonan Fujisawa Campus	Chien, Kumar, Miyahara, Yuh, Zheng	4 Oct 2004
Ministry of Economy, Trade, and Industry (METI)	Sanderson, Yuh	8 Oct 2004
Nagoya University	Chien, Dastoor, Sanderson	7 Oct 2004
NEC/Toshiba Space Systems Division	Ambrose, Bekey, Chien, Lavery, Wilcox	7 Oct 2004
Osaka University	Chien, Dastoor, Sanderson	6 Oct 2004
Ritsumeikan University	Chien, Dastoor, Sanderson	6 Oct 2004
Sony Corporate R&D Laboratory	Ambrose, Bekey, Kumar, Lavery, Wilcox, Zheng	5 Oct 2004
Tokyo Institute of Technology	Ambrose, Chien, Wilcox	4 Oct 2004
University of Tokyo — Department of Mechano Informatics	Sanderson, Yuh	8 Oct 2004
University of Tokyo — Underwater Technology Research Center	Ambrose, Lavery, Wilcox, Yuh	9 Oct 2004

Table 1.1. (Continued).

Site	Panelists	Date
Tsukuba University	Ambrose, Bekey, Lavery, Wilcox, Yuh	9 Oct 2004
Waseda University	Ambrose, Bekey, Kumar, Miyahara, Sanderson, Wilcox, Yuh, Zheng	7 Oct 2004
<i>Korea</i>		
Electronic and Telecommunications Research Institute (ETRI)	Ambrose, Bekey, Chien, Zheng	12 Oct 2004
Hanool Robotics	Ambrose, Bekey, Chien, Kumar, Sanderson, Weber, Wilcox, Yuh, Zheng	12 Oct 2004
Korea Advanced Institute of Science and Technology (KAIST)	Ambrose, Bekey, Chien, Wilcox, Yuh	12 Oct 2004
Korea Institute of Science and Technology (KIST)	Ambrose, Wilcox, Yuh, Zheng	12 Oct 2004
Korea Research Institute of Ships and Ocean Engineering (KRISO)/Korea Ocean Research & Development Institute (KORDI)	Sanderson, Wilcox, Yuh	12 Oct 2004
Pohang Science and Technical University (POSTECH)	Ambrose, Chien, Sanderson, Wilcox, Yuh, Zheng	13 Oct 2004
Samsung Mechatronics Center	Ambrose, Chien, Wilcox, Yuh, Zheng	12 Oct 2004
Seoul National University	Bekey, Chien, Sanderson, Weber	11 Oct 2004
Sungkyunkwan University	Bekey, Chien, Sanderson, Weber	11 Oct 2004

they provided a general framework for the discussions. The questions were the following:

1. How long has your laboratory been in existence?
2. What fraction of the work in this lab concerns robotics?
3. How is your work supported — Government, university, or industry funds?
4. Is the level of support adequate for the work you plan to do?
5. What interactions do you have with academia, government, and industry, and with the labs in other countries?
6. What are the other major research groups *in your country* that are working in your area of research?

7. What are the other major research groups *outside of your country* that are working in your area of research?
8. How do you assess robotics research in the United States as compared to your country? In your field of robotics, do you think your country is leading the United States?

In September 2005, the results of the study were presented to the nation at a press conference and workshop held at NSF. In January 2006, “virtual site visits” were conducted with two leading laboratories in Australia. The directors of these laboratories submitted replies to the questions from the team and provided pictures of the robots they developed. The final report was published by WTEC in February 2006 (<http://wttec.org/robotics>).

Based on the study, it was concluded that:

- Robotics is a very active field, worldwide.
- Japan, Korea, and the European Community invest significantly larger funds in robotics research and development for the private sector than the United States.
- There are numerous start-up companies in robotics, both in the United States and abroad. Venture capital appears to be available.
- The United States currently leads in such areas as robot navigation in outdoor environments, robot architectures (the integration of control, structure, and computation), and in applications to space, defense, underwater systems, and some aspects of service and personal robots.
- Japan and Korea lead in technology for robot mobility, humanoid robots, and some aspects of service and personal robots including entertainment.
- Europe leads in mobility for structured environments, including urban transportation. Europe also has significant programs in eldercare and home service robotics.
- Australia leads in commercial applications of field robotics, in such areas as cargo handling and mining, and in the theory and application of localization and navigation.
- In contrast with the United States, Korea and Japan have national strategic initiatives in robotics; the European community has EC-wide programs. In the United States, there is coordination only in military robotics. The US Department of Defense has a Joint Robotics Program (JRP) Master Plan. The United States lost its pre-eminence in industrial robotics at the end of the 1980s, so that nearly all robots for

welding, painting, and assembly are imported from Japan or Europe; it may lose its leading position in other aspects of robotics as well.

Some examples of funding disparities: In the United States, NSF funding for robotics is about \$10 million per year. Annual funding for military robotics in the United States is estimated to be more than \$200 million per year. In Japan, robotics useful in home and town was selected as one of the 62 Priority Technologies selected by Japanese Government's Council for Science and Technology Policy (CSTP) for Japan's Third S&T Basic Plan and its Priority Technologies, JFY2006-2010. In Korea, robotics has been selected as one of the 10 areas of technology to be "engines for economic growth"; the total funding for robotics is about \$80 million per year. In Europe, a new program called "Advanced Robotics" has been funded at about \$100 million for 3 years.

A summary of the areas of major strength in various aspects of robotics in the United States, Asia, and Europe is given in Table 1.2. The "INPUT" section refers to the kinds of resources and organizations that produce R&D, while "OUTPUT" refers to the outcomes of research, into key robotic products or applications.

Table 1.2. Qualitative robotics comparison chart.

Area	Degree or Level of Activity			
	United States	Japan	Korea	Europe
<i>Input</i>				
Basic, university-based research (Individual, groups, centers)	*****	***	***	***
Applied, industry-based research (corporate, national labs)	**	*****	****	****
National or multinational research initiatives or programs	**	*****	*****	****
University-industry-government partnerships; entrepreneurship	**	*****	*****	****
<i>Output</i>				
Robotic vehicles: military and civilian	****	**	**	**
Space robotics	***	**	N/A	***
Humanoids	**	*****	****	**
Industrial robotics: manufacturing	**	*****	**	****
Service robotics: nonmanufacturing	***	***	****	***
Personal robotics: home	**	*****	****	**
Biological and biomedical applications	****	**	**	****

A number of trends in technology are expected to have a major impact on robotics in the near future. The DARPA Grand Challenge in the United States in 2005 and 2007 demonstrated the ability of autonomous vehicles to travel at average speeds in excess of 30 mph over unknown terrain, and in the presence of a number of hazards and obstacles. The winning vehicles integrated sensors (including GPS), complex and intelligent vision systems, and sophisticated navigation algorithms to accomplish the task. These and other aspects of the so-called “Intelligent Vehicle Technology” are expected to influence the development of autonomous robotic vehicles in the near future. Developments in nanotechnology may lead to *nanorobotic systems*, capable of self-assembly or perhaps manipulation of individual molecules for research in genetics and related areas. We have cited robotic surgery as a major current area of application. We expect that in the future, increasingly autonomous systems will be able to operate within the body to identify and perhaps remove tumors. New imaging techniques, like fMRI, combined with nanorobotics, may make possible dramatically new and different studies of brain function. Networks of sensors distributed throughout the environment may allow distributed robotic systems to interact and function as a collective system in the solution of environmental and other problems. This is just a sampling of the exciting potential of robotics. Clearly, this is the age of robotics and we expect it to have an increasingly important effect on our lives, both as individuals and as societies.

The remainder of this book is organized into six chapters concerned with specific major application areas. Each chapter:

- defines the area;
- indicates why it is important;
- describes the major technologies required;
- points out major applications with examples;
- outlines the major challenges, both present and future;
- summarizes major activities in the United States, Korea, Japan, and the European countries visited; and
- provides a qualitative comparison between R&D activities in these regions.

The specific topics are:

Chapter 1: Introduction

Chapter 2: Robotic vehicles

Chapter 3: Space robotics

Chapter 4: Humanoid robots

Chapter 5: Industrial, service, and personal robots

Chapter 6: Robotics in biology and medicine

Chapter 7: Networked robots

The Appendix contains short biographies of the members of the study team, who are also the authors of this volume.