Project in History of Control: The History of Robot Control

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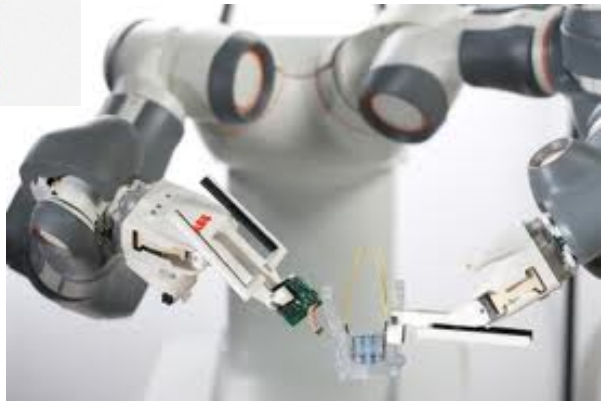
Introduction

- The authors are performing research within the robotics field
- Example of research areas: Assembly, machining, and force control of industrial robots
- Interdisciplinary subject: mechanics, sensors, control, software, and neuroscience



Major organizations in the field

- IEEE Robotics and Automation Society (RAS)
- IFAC Technical Committee 4.3 – Robotics, Mechatronics and Components
  - For a long time focused on European activities
- International Federation of Robotics (IFR)
  - Focus on industry
- Robotics Committee, Dynamic Systems & Control Division, ASME

Foundation of the IEEE RAC

- In the middle of the 1980's, robotics was identified as a subject in itself
- Industry exhibiting an increasing interest in robotics
- Increasing number of publications directly related to robotics submitted to the conferences and journals of the Control Systems Society at the time
- Foundation of the Robotics and Automation Council
- Initially, three main activities:
  - IEEE Journal of Robotics and Automation
  - IEEE RAC Newsletter
  - IEEE International Conference on Robotics and Automation (ICRA)

Transformation into an IEEE Society

- IEEE Robotics and Automation Council became IEEE Robotics and Automation Society, Jan 1st, 1989.
- Objectives as described in the Constitution:
  - “Its objectives shall be scientific, literary and educational in character. The Society shall strive for the advancement of the theory and practice of robotics and automation engineering and science and of the allied arts and sciences, and for the maintenance of high professional standards among its members[...]"

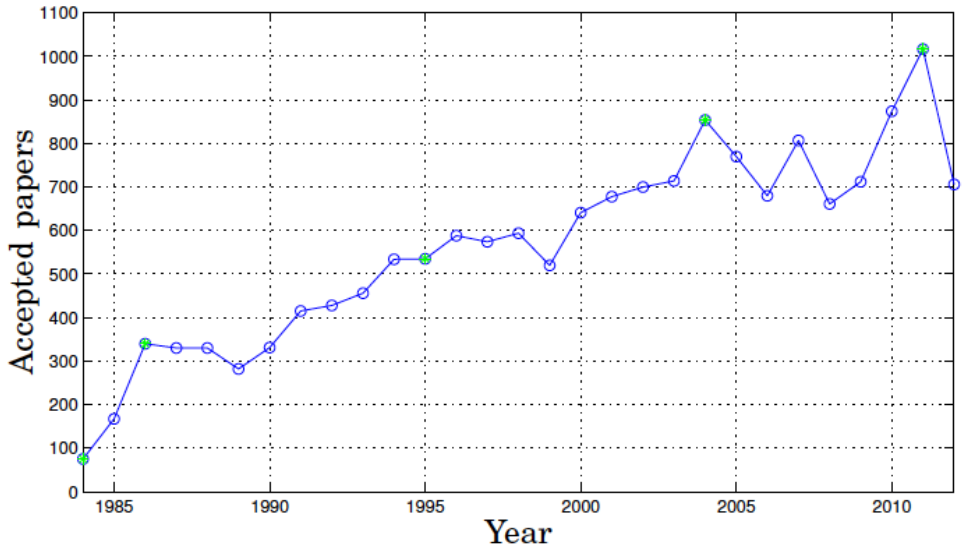
Former presidents of RAS at ICRA2012

Characteristics of the young RAS

- Strong collaboration between academy, research institutes and industry already from the beginning – significant for the whole robotics field
- Initially, the participation in the ICRA conference was higher from industry and research institutes than from universities
- At the first ICRA conferences mainly participants from North America, but later spread to Europe and Asia
- Rapid expansion of interest from academy in the end of the 1980's: Journal changed from quarterly to bimonthly publication already two years after the first volume in 1984

IEEE International Conference on Robotics and Automation

- The flagship conference of IEEE RAS
- Annually since 1984 – North America, Europe and Asia
- Rapid expansion after the first conference
- Analysis of trends in paper subjects at ICRA



Sampling of ICRA conferences

- Five conferences have been subject to sampling

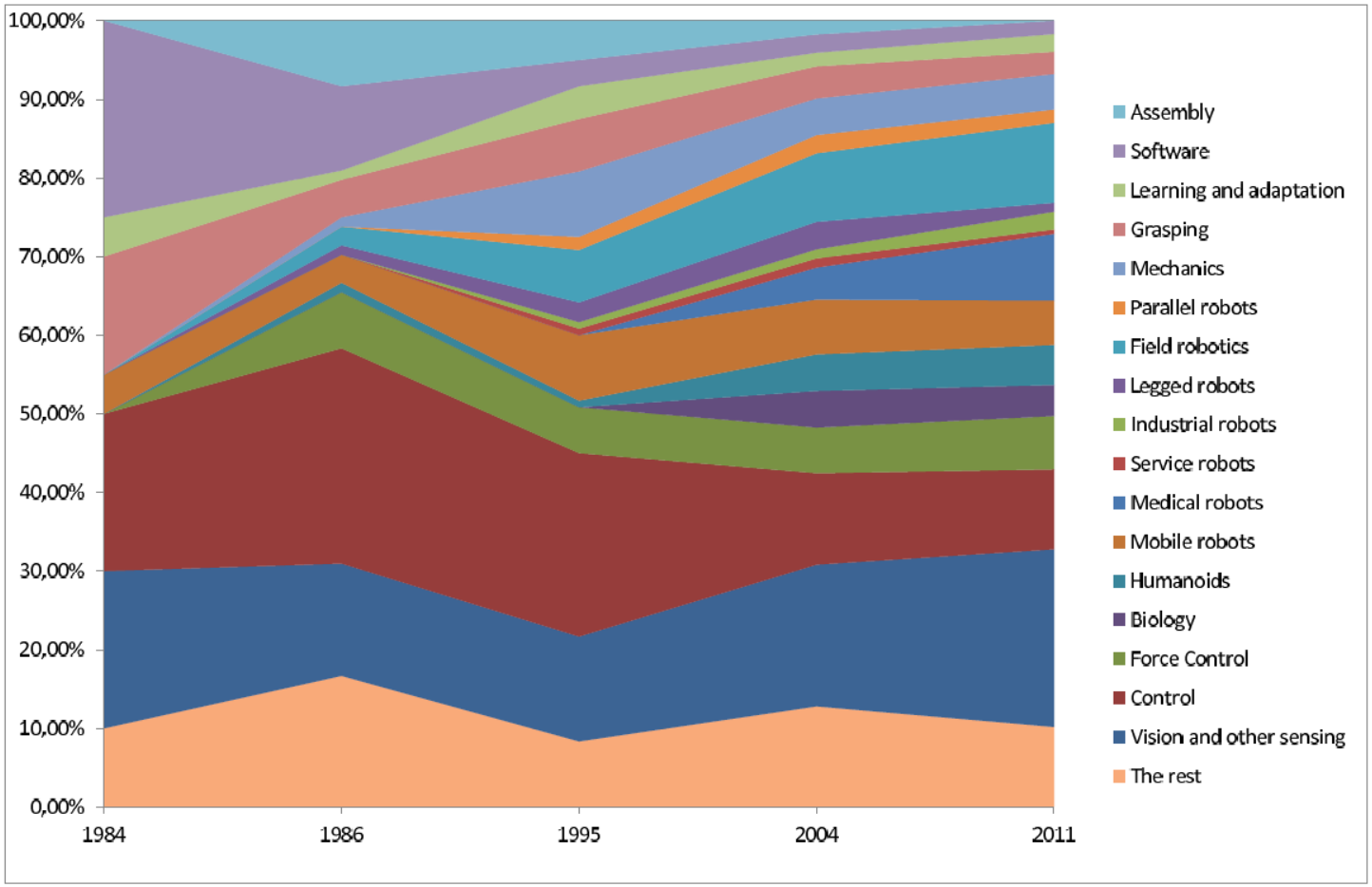
1984	Atlanta, Georgia, USA
1986	San Francisco, California, USA
1995	Nagoya, Japan
2004	New Orleans, Louisiana, USA
2011	Shanghai, China

- Goal of the sampling is to study the development of the robotics field over the three past decades

Classification of subjects

Subject name	*Also contains*
Vision and other sensing	SLAM, human detection, recognition, visual navigation, range sensing, sensor fusion, localization, inspection
Control	Motion and path planning, cooperative control, collision avoidance, manipulation planning, discrete event systems
Force control	Force control, haptics, teleoperation, variable stiffness/flexible arms, impedance control, contact motion
Biology	Biology inspired robots, behavior based systems
Humanoids	Human/robot interaction
Mobile robots	Autonomous navigation, wheeled robots, nonholonomic systems
Medical robots	Surgical robots, rehabilitation robotics
Service robots	Amusement robots
Industrial robots	Industrial automation, factory automation
Legged robots	Walking robots
Field robotics	Aerial robotics, space robotics, underwater robotics, climbing robots, micro/nano robots, surveillance/search/rescue robots, specialized robot systems, UAV
Parallel robots	
Mechanics	Underactuated robots, actuators, robot design, redundant robots, soft material robots, robot design
Grasping	Dexterous manipulation, hands, tactile sensing
Learning and adaptation	
Software	Simulation
Assembly	Assembly skills, assembly planning, assembly applications, manufacturing
The rest	Agent based systems, calibration and identification, modular robots, dynamics and kinematics formulation, distributed robot systems, networked robots, general robotics and applications, robot safety, robotics education

Development of subjects over time



Development of subjects over time (cont'd)

- Based on the sampling of the sessions at the ICRA conference, the subjects with decreasing, constant, and increasing trend have been identified

Decreasing trend	*Constant*	*Increasing trend*
Software	Learning and adaptation	Parallel robots
Assembly	Grasping	Field robotics
Control	Mechanics	Biology
	Service robots	Vision and other sensing
	Mobile robots	Medical robots
	Legged robots	Humanoids
	The rest	Industrial robots
		Force control

Landmark articles in the field of robot control

- Using the database SciVerse Scopus, the five most cited articles in the field have been identified:

1. R. A. Brooks (MIT Artifical Intelligence Lab, MIT): "Robust Layered Control System for a Mobile Robot", IEEE J. of Robotics and Automation, 1986.
2. O. Khatib (Stanford University, USA): "Real-Time Obstacle Avoidance for Manipulators and Mobile Robots", Int. J. of Robotics Research, 1986.
3. S. Julier (IDAK Industries), J. Uhlmann (Oxford University, UK), and H. F. Durrant-Whyte (University of Sydney, Australia): "A new method for the nonlinear transformation of means and covariances in filters and estimators", IEEE Trans. on Automatic Control, 2000.
4. T. McGeer (Simon Fraser University, Canada): "Passive dynamic walking", Int. J. of Robotics Research, 1990.
5. T. Balch (Carnegie Mellon University, USA) and R. C. Arkin (Georgia Institute of Technology, USA): "Behavior-based formation control for multirobot teams", IEEE Trans. on Robotics and Automation, 1998.

Landmark articles in the field of robot control (cont'd)

- Landmark articles on the top-twenty list of most cited articles:

  - M. H. Raibert (Boston Dynamics, USA) and J. J. Craig (Stanford University, USA): "Hybrid Position/Force Control of Manipulators", Trans. of the ASME J. of Dynamic Systems, Measurement and Control, 1981.
  - O. Khatib (Stanford University, USA): "Unified Approach for Motion and Force Control of Robot Manipulators: The Operational Space Formulation", IEEE J. of Robotics and Automation, 1987.
  - J.-J. E. Slotine and L. Weiping (MIT, USA): "On the Adaptive Control of Robot Manipulators", Int. J. of Robotics Research, 1987.

Influential researchers in the field

- Most productive researchers according to SciVerse Scopus database:

1. T. Fukuda (Nagoya University, Japan)
2. K. Ohnishi (Keio University, Tokyo, Japan)
3. G. Hirzinger (Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany)
4. S. Arimoto (Riken, Wako, Japan)
5. D. M. Dawson (Clemson University, USA)

Successful robotic labs in the world

- DLR, Munich, Germany
- KAIST, South Korea
- Nagoya University, Nagoya, Japan
- JPL, Los Angeles, USA
- MIT, Boston, Massachusetts
- AI Lab at Stanford University, USA

Successful robot manufacturers

- Many examples of successful transfer of knowledge from universities and research institutes to industry, which resulted in commercial products
- Some examples:
  - ABB Robotics
  - KUKA Robotics
  - COMAU
  - FANUC
  - Motoman Yaskawa
  - Reis Robotics






Successful robot companies

- iRobot
- Willow Garage
- Boston Dynamics
- Honda

Conclusions

- Increasing interest from academy and industry in the robotics field
- Advanced applications of robotics emerging:
  - Humanoid robots
  - Biology-inspired robots
  - Human-robot interaction
- Certainly an expanding research area

References

- IEEE Robotics and Automation Society Constitution, 2011.
- Antal K Bejczy. The Birth of the RAS. *Robotics & Automation Magazine, IEEE,* 14(1):104–108, 2007
- Antal K Bejczy. The IEEE Robotics and Automation Society History. In *IEEE Conference on the History of Technical Societies,* pages 1–7. *IEEE*, 2009