ROBOTICS

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Summary

This chapter introduces the basics of robotics. The robotics Institute of America defines a robot as *a reprogrammable multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks*. From the historical point of view, robotics is a relatively new field of modern technology that crosses traditional engineering boundaries. Accordingly, robotics can be considered as an interdisciplinary field that ranges in scope from the design of mechanical and electrical components to sensing technologies, computer systems, artificial intelligence, and human interface. In this way, understanding robots and their applications requires various fields of knowledge such as mechatronics, computer science, informatics, and mathematics. Basically, creating autonomous robots requires the capability to plan motions without human assistance. The researches of robotics are not only concerned with the development of robot, but also deeply related with understanding human life and intelligence. First, the field of robotics is surveyed from the historical viewpoint. Next, mechanism and components of robots are explained. Finally, the research streams of robotics and applications are introduced.

1. Introduction

A number of researchers in robotics have tried to develop machines that interact adaptively with an unknown or unstructured environment in order to perform a task given by a human. The notion of robots can be traced back to medieval times. In medieval times, various human-like figures were made with the development of complex hidden mechanisms. The automatons like the *clock jack* created the illusion of self-motion without human assistance. In the 18th century, miniature automatons became popular as toys for rich people. They were made to look and move like human beings or small animals. In literature, Mary Shelly wrote *Frankenstein*, a story about the construction of a human-like creature. Thus, the root of robots can be found not only in toys and interiors, but also in literature.

The term of '*robot*' was introduced in 1921 by K.Capek's Play, *R.U.R.* (Rossum's Universal Robots). *Robot* comes from the Czech word '*robota*', that means forced labor. In the play, a robot was developed to replace human workers in manufacturing systems, but the robot turned against human beings in the end. Developing human-like machines has been a human dream for a long time. I. Asimov coined the word robotics in the early 1940. The Three Laws of Robotics proposed by him are as follows;

1. A robot may not injure a human being, or through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

The robot in modern day was born with the arrival of digital computers. Afterward the term of robot has been used to various mechanical devices, such as teleoperators, autonomous land rovers, underwater vehicles, and others. Anything that operates with some degree of autonomy under computer control has been called a *robot* in a sense. Actually, the definition of a robot varies with references. In the Cambridge International Dictionary of English a robot is defined as *a machine used to perform jobs automatically which is programmed and controlled by a computer*. In the American Heritage Dictionary, a robot is defined as *a mechanical device that sometimes resembles a human being and is capable of performing a variety of often complex human tasks on command or by being programmed in advance*. The robotics Institute of America defines a robot as *a reprogrammable multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks*.

The term of robotics refers to the study and use of robots. M. Brady defines robotics as the intelligent connection of perception to action. J. Hopcroft defines as follows; robotics is the science of representing and reasoning about the motion and action of physical objects in the real world. The key element in the above definitions is the reprogrammability of a robot, *i.e.*, adaptability and flexibility. From the historical point of view, robotics is a relatively new field of modern technology that crosses traditional engineering boundaries. Accordingly, robotics can be considered as an interdisciplinary field that ranges in scope from the design of mechanical and electrical components to sensing technologies, computer systems, artificial intelligence, and human interface. In this way, understanding robots and their applications requires various fields of knowledge such as mechatronics, computer science, informatics, and mathematics. One of important aims in the development of robots is to enable robots to interact with their environment instead of human beings. Furthermore, the ultimate goal is the development of machines with near or even beyond human levels of intelligent and physical abilities such as perceiving, acting, learning, planning, and communicating. Basically, creating autonomous robots requires the capability to plan motions without human assistance. A number of researchers in robotics and artificial intelligence have dealt with researches of motion planning of robots so far. The researches of robotics are not only concerned with the development of robot, but also deeply related with understanding human life and intelligence. The aims of human-like robots are to understand human behavior and to build humanoid, while the aims of artificial intelligence are to understand intelligence and to build intelligent systems. Furthermore, various robots have been applied in manufacturing, nuclear plants, space exploration, welfare and entertainment. In this way, the researches of robotics have branched into various streams. We present below the history of robotics, the mechanism and components of robots, and research streams and applications of robotics.

2. Historical Perspective

The study and development of robot mechanisms can be traced back to the mid-1940s. The robot was born out from three earlier technologies: servo-mechanisms theory, *teleoperators*, and *numerically controlled machine tools*. Tele-operators, or master-slave manipulators, were developed during the Second World War to handle radioactive materials. The 'master-slave' systems were designed to reproduce accurately hand and arm motions of a human operator. The master manipulator was guided through a sequence of actual motions of the human operator, while the slave manipulator duplicated the motion of the master manipulator as closely as possible. Subsequently, a force feedback mechanism was added by coupling the motion of the master and slave manipulators mechanically in order that the human operator was able to feel forces as they developed between the slave manipulator and its environment. Computer numerical control was developed for the high precision required in the machining of certain items. The first robots essentially combined the mechanical linkages of the tele-operator with the autonomy and programmability of computer numerical control machines. Basically, they are computer-controlled manipulators including arms and hands, and are also supported by the servo-control and sensing technologies.

Most of industrial robots do not have human-like appearance. The robots usually look very different from a human being. However, industrial robots are very successful at simple repetitive tasks that are typical of assembly lines. Application of industrial robots includes painting and welding in automotive assembly lines, and dismantling old nuclear power plants. In the mid-1950s, G. Devol developed a device, 'programmed articulated transfer device' (programmable manipulator). The device was able to exhibit repeatable 'point-to-point' motions. The first commercial computer-controlled robot was introduced in 1961 by Unimation, Inc., and a number of industrial and experimental devices followed suit during the next 15 years. The first robot is now in the Smithsonian Institute. The key element of this robot was to use a computer in conjunction with a manipulator to produce a machine that could be 'taught' to carry out a variety of tasks automatically. While programmed robots were offered as a novel and powerful tools in manufacturing systems, it became evident that the flexibility of these machines could be enhanced significantly by using sensory feedback in the 1960s. Furthermore, walking machines with legs were developed using the same technologies. In 1968, Kawasaki Heavy Industries, Ltd. in Japan took a license under all of Unimation Inc.'s Technology. Figure 1 show a picture of Kawasaki Unimate 2000. Subsequently, the robots became popular in the automotive industry, and were employed to help factory operators. Figure 2 shows a picture of EA100 developed by Kawasaki Heavy Industries, Ltd.

Figure 1: Kawasaki Unimate 2000 (Kawasaki Heavy Industries, Ltd., 1969)

The robots can be also divided into some types from the historical and functional point of view. First-generation robots have the capability to learn a sequence of manipulative actions choreographed by human operator using a teach-box. These robots are equipped with little or no external sensors for obtaining the information of its working environment. As a result, robots are used mainly in relatively simple and repetitive tasks. Therefore, their workspace must be prearranged to accommodate their actions. Second-generation robots are designed to accomplish tasks such as spot welding, paint spraying, arc welding, and some assembly.

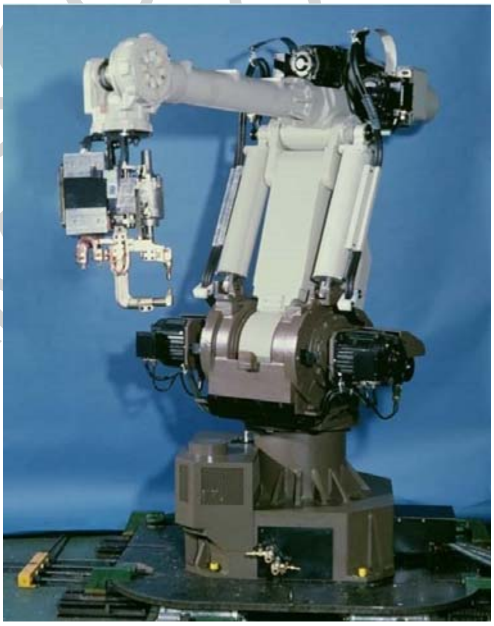

Figure 2: EA100 (Kawasaki Heavy Industries, Ltd., 1982)

Some simple sensors including force, torque, and proximity, could be equipped in robots.

Furthermore, in 1970s, a number of researches focused on the use of external sensors to enhance manipulative capability. Third-generation robots were developed with incorporation with multiple computer processors in 1980s. A typical robot system is composed of a separate low-level processor for each degree of freedom and master computer supervising and coordinating these processors like distributed hierarchical processing. While each low-level processor receives internal sensory signals and plays the role of the servo-system controlling that degree of freedom, the master computer coordinates the motions of each degree of freedom. Furthermore, the master computer performs coordinate transformation calculations to accommodate different frames of reference to deal with its external environment including other robots and machines. In this way, robots have been pervasive in certain application areas such as automobile painting and welding and electronic assembly.

On the other hand, various types of robots have been developed for research and education. In 1996, Honda Motor Co., Ltd., demonstrated the Honda Humanoid P2, but the humanoid robot research and development program began in 1986. Figure 3 shows the first experimental model of a biped locomotion robot. The P2, 1,820mm in height and 210kg in weight, features a computer unit, motor-drive system, battery and wireless apparatus inside the body section (Figure 4). Furthermore, the P2 is equipped with various sensors such as cameras, gyroscopes, accelerometers, and force sensors at the wrists and feet. The humanoid robot with two legs and two arms is designed for use in a typical domestic environment.

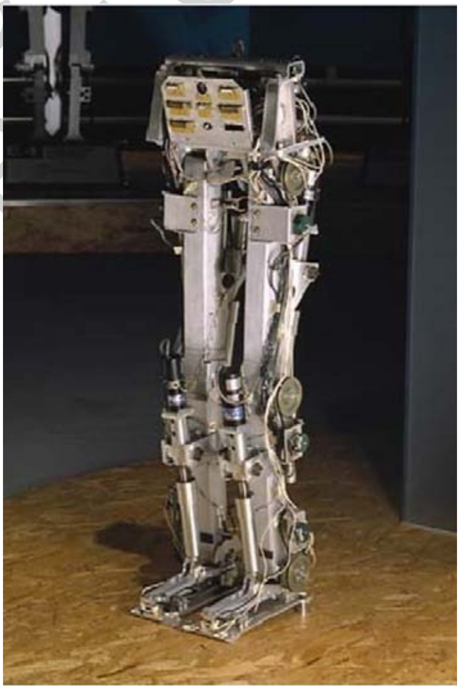

Figure 3: E0 (Honda Motor Co., Ltd., 1986)

Figure 4: The Honda humanoid robot P2 (Honda Motor Co., Ltd., 1996)

2.1. Mobile and Walking Robots

The function of a mobile robot is to move from place to place automatically, i.e., without human intervention. Various types of mobile robots have been developed until now. For example, a miniature robot, Khepera, was designed on the basis of miniaturization, modular open architecture, expandability, and others, and has often been used for robotic researches and education (Figure 5).

Various methods for path planning of a mobile robot have been proposed in intelligent robotics so far. In general, path planning is performed on a built map, but a robot might deal with unknown environment.

Sensor-based navigation enables a robot to explore an unknown environment and build a map of the environment. Most of the researches on vision-based navigation have focused on the problem of building full or partial three-dimensional representations of the environment.

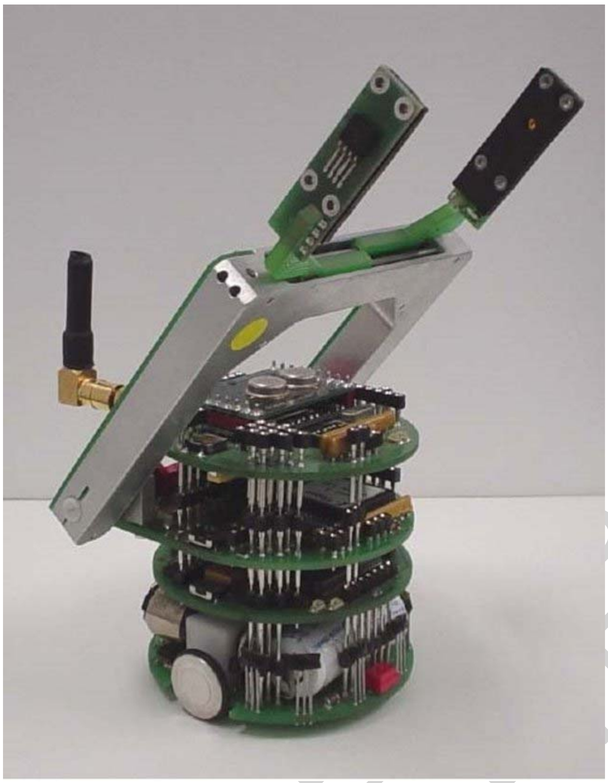

Figure 5: A miniature mobile robot; Khepera

In near future, human beings will share the living space with robots. Therefore, robots require the moving capability in various environments for adapting to human living space. Walking machines are complex systems that incorporate sensing, control, mechanisms, and dynamic analysis. Raibert and his colleagues first studied the control of a running machine with one leg in the plane. They introduced a simple feedback algorithm for a planar one-legged hopping machine in order to regulate its desired hopping height, body posture, and forward velocity based on their physical insight. This study was extended to achieve running in three dimensions. A biped locomotion is generally known as one of the flexible moving methods. The dynamic walking for biped locomotion robots has been accomplished until now. To control the biped locomotion robots is very difficult, since the reference trajectory of the biped locomotion robots must be generated without falling down. Therefore, the walking robots such as biped and quadruped robots should be controlled under the consideration of their current configurations and grand contacting states, while the robots fixed on the ground such as manipulators can pose any possible configurations without considering their current configurations.

Brachiating is another moving method. A brachiating robot dynamically moves from handhold to handhold like a long armed ape swinging its arms. A brachiating and a legged locomotion system share the requirement of an oscillatory exchange of kinetic energy and potential energy in the gravitational field. Fukuda and his colleagues developed a brachiating robot in 1985 (Figure 6 (a)).

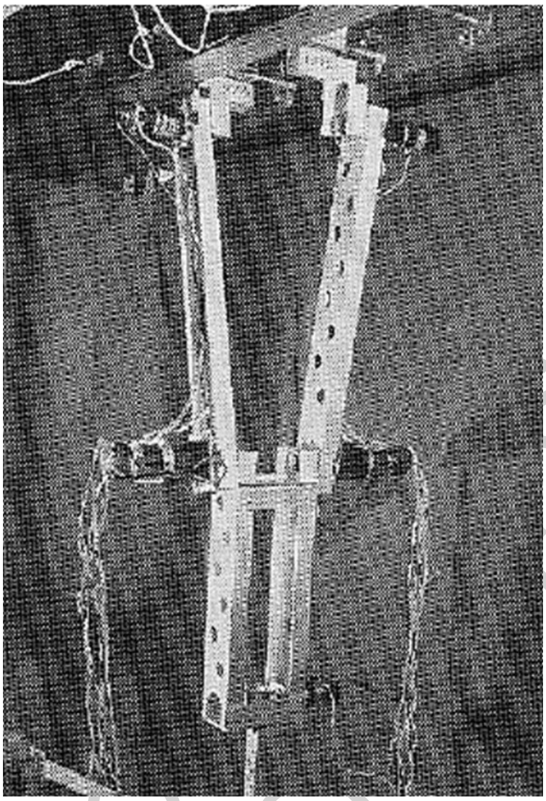

Figure 6 (a): Brachiator I-1985

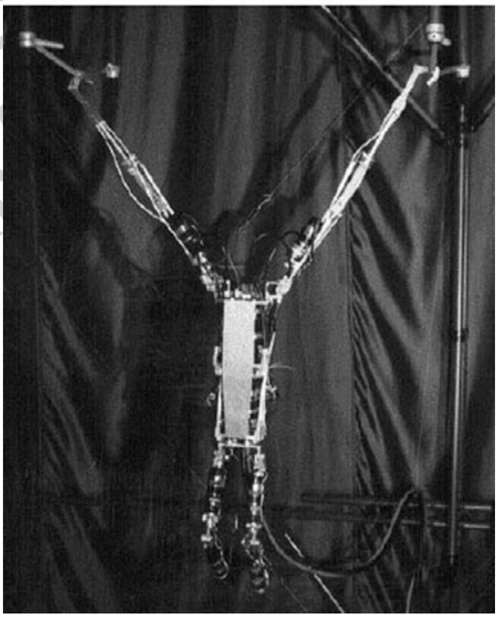

Figure 6 (b): 12 DOF Brachiator III-1996

Figure 6 (c): Gorilla II- Multi-locomotive robot

Furthermore, they developed a brachiating robot with 12 degrees of freedom in 1996 (Figure 6 (b)). Recently, they developed a multi-locomotive robot that can select a proper type of locomotion according to its environment (Figure 6 (c)).

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Bibliography

Ahmadabadi, M.N. and Nakano, E. (2001), *A "Constrain and Move" Approach to Distributed Object Manipulation*, IEEE Transaction on Robotics and Automation, Vol.17, No.2, pp.157-172.

Albus, J.S. and Meystel, A.M. (2001), *Engineering of Mind*, John Wiley & Sons, Inc. [This book discusses "what is mind?", and introduces the basics of intelligent systems.]

Anderson, R. L. (1988), *A robot Ping-Pong Player: Experiment in Real-Time Intelligent Control*, MIT Press.

Baron, L. and Angeles, J. (2000), *The Kinematic Decoupling of Parallel Manipulators Using Joint-Sensor Data*, IEEE Transaction on Robotics and Automation, Vol.16, No.6, pp.644-651. [This paper shows mathematical formulation of parallel manipulator.]

Bicchi, Antonio (2000), *Hands for Dexterous Manipulation and Robust Grasping: A Difficult Road Toward Simplicity*, IEEE Transaction on Robotics and Automation, Vol.16, No.6, pp.652-662.

Brady, M. and Paul, R. (1984), *Robotics Research: The First International Symposium*, The MIT Press. [This proceedings volume includes invited papers of pioneers of robotic research.]

Brooks, R. A. (1983), *Planning Collision Free Motions for Pick and Place Operation*, Robotics Research, MIT Press, pp.5-38. [This paper proposes a roadmap method for motion planning of robots.]

Davidor, Yuval. (1991), *A genetic Algorithm Applied to Robot Trajectory Generation*, In Handbook of Genetic Algorithms, Van Nostrand Reinhold, pp.144-165. [This chapter deals with the applications of genetic algorithms to robotics.]

Dudek, G. and Jenkin, M. (2000), *Computational Principles of Mobile Robotics*, Cambridge University Press. [This book introduces the basics and technologies of mobile robots.]

Fogel, D.B. (1995), *Evolutionary Computation*, New York, IEEE Press. [This book deals with the mathematical basics and applications of evolutionary computation.]

Fu, K.S., Gonzalez, R.C., and Lee, C.S.G. (1987), *Robotics*, McGraw-Hill Book Company. [This book deals with the introduction to robotics and vision-based sensing.]

Fukuda, T. and Kubota, N. (1999), *Fuzzy Control Methodology: Basics and State of Art*, in Soft Computing in Human-Related Sciences (H.N.Teodorescu, A.Kandel, and L.C.Jain (eds.)), pp.3-35. [This chapter deals with the introduction to fuzzy control.]

Fukuda, T., and Ueyama, T. (1994), *Cellular Robotics and Micro Robotic Systems*, World Scientific Series in Robotic and Automated Systems Vol.10, World Scientific. [This book introduces the basics of reconfigurable cellular robotics and micro robotics.]

Fukuda, T., Kubota, N., and Arakawa, T. (1997), *GA Algorithms in Intelligent Robots*, in Fuzzy Evolutionary Computation, Kluwer Academic Publishers, pp.81-105. [This chapter deals with genetic algorithms for intelligent robots.]

Fukuda, T., Saito, F., and Arai F. (1991), *A Study on the Brachiation type of Mobile Robot (Heuristic Creation of Driving Input and Control Using CMAC)*, IEEE/RJ International Workshop on Intelligent Robots and Systems, pp.478-483. [This paper shows learning method for a brachiation robot.]

Goldberg, D.E. (1989), *Genetic Algorithm in Search, Optimization, and Machine Learning*, Massachusetts: Addison Wesley. [This book deals with the basics, methodologies, and applications of genetic algorithms.]

Han, L., Trinkle, J., and Li., Z. (2000), *Grasp Analysis as Linear matrix Inequality Problems*, IEEE

Transaction on Robotics and Automation, Vol.16, No.6, pp.663-674.

Khatib, O. (1986), *Real-Time Obstacle Avoidance for Manipulators and Mobile Robots*, Robotics and Research, Vol.5, No.1, pp.90-98.

Kosuge, K., Hirata, Y., Asama, H., Kaetsu, H., and Kawabata, K. (1999), *Motion Control of multiple Autonomous Mobile Robots handling A Large Object in Coordination*, Proc. of IEEE International Conference on Robotics and Automation, pp.2666-2673.

Latombe, Hean-laude (1991), *Robot Motion Planning*, Kluwer Academic Publishers. [This book deals with motion planning for robots.]

Meystel, A.M. and Albus, J.S. (2002), *Intelligent Systems*, John Wiley & Sons, Inc. [This book introduces the basics of intelligent systems and robots.]

Nakamura, Yoshihiko (1991), *Advanced Robotics - Redundancy and Optimization*, Addison-Wesley Publishing Company. [This book deals with dynamics and optimization for redundant robots.]

Paul, R.P. (1981), *Robot Manipulators: Mathematics, Programming, and Control*, The MIT Press.[This book shows mathematical foundation of control for robot manipulators.]

Portman, V., Sandler, B.-Z., and Zahavi, E. (2000), *Rigid* 6×6 *Parallel Platform for Precision 3-D Micromanipulation: Theory and Design Application*, IEEE Transaction on Robotics and Automation, Vol.16, No.6, pp.629-643. [This paper shows mathematical formulation of parallel manipulator.]

Raibert, M.H. (1986), *Legged Robots that Balance*, MIT Press. [This book shows mathematical and practical theories for walking robots.]

Russell, S.J. and Norvig, P. (1995), *Artificial Intelligence*, Prentice-Hall, Inc. [This book deals with methodologies of artificial intelligence from various viewpoints.]

Saito, F. and Fukuda, T. (1996), *A Multi-link Brachiation Robot*, IEEE International Conference on Robotics and Automation, Conference Video Proceedings.

Spong, M.W. and Vidyasagar, M. (1989), *Robot Dynamics and Control*, John Wiley & Sons. [This book deals with dynamics and control of robots.]

Vukobratovic, M., Brovac, B., Surla, D., and Stokic, D. (1990), *Biped Locomotion*, Springer-Verlag. [This book introduces the basics of biped locomotion robots.]

Wu, J.-L. and Kawamura, S. (2000), *Quantitative Analysis of Human Tactile Illusory Characteristic Under Visual Environment and a Haptic Device of Two-Dimensional Curved Surface*, IEEE Transaction on Robotics and Automation, Vol.16, No.6, pp.762-771.

Xie, Ming (2003), *Fundamentals of Robotics, Series in Machine Perception and Artificial Intelligence*, World Scientific. [This book introduces the basics of sensors actuators, electromechanical systems, control systems, computer systems, visual sensing systems used in robotics.]

Xu and Kanade (1993), *Space Robotics: Dynamics and Control*, Kluwer Academic Publishers.

Biographical Sketches

Toshio Fukuda graduated from Waseda University in 1971 and received the Master of Engineering degree and Dr. Eng. from the University of Tokyo in 1973 and 1977, respectively. Meanwhile, he studied at the graduate school of Yale University from 1973 to 1975. In 1977, he joined the National Mechanical Engineering Laboratory and became Visiting Research Fellow at the University of Stuttgart from 1979 to 1980. He joined the Science University of Tokyo in 1982, and then joined Nagoya University in 1989. Currently, he is Professor of Department of Micro System Engineering and Department of Mechano-Informatics and Systems, Nagoya University, Japan, mainly engaging in the research fields of intelligent robotic system, cellular robotic system, mechatronics and micro robotics. He is an author of six books, editing five books and has published over 1,000 technical papers in micro system, robotics, mechatronics and automation areas. He was awarded IEEE Fellow, SICE Fellow (1995), IEEE Eugene Mittlemann Award (1997), Banki Donat Medal form Polytechnic University of Budapest, Hungary (1997), Medal from City of Sartillo, Mexico (1998), IEEE Millennium Medal (2000) and JSME Fellow (2001). He is the Vice President of IEEE IES (1990 - 1999), IEEE Neural Network Council Secretary (1992 -1993), IFSA Vice President (1997 -), IEEE Robotics and Automation Society President (1998 - 1999), current Editor-in-Chief, IEEE / ASME Transactions on Mechatronics (2000 -), current IEEE Division X Director (2001-), and current IEEE Nanotechnology Council President (2002-)

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