Robotics

Concepts, Methodologies, Tools, and Applications

Information Resources Management Association

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Robotics:

Concepts, Methodologies, Tools, and Applications

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Volume I

Preface

The constantly changing landscape of Robotics challenges experts and practitioners to stay apprized of the field's most up-to-date research. That is why Information Science Reference is pleased to offer this three-volume reference collection that will empower students, researchers, and academicians with a strong understanding of critical issues within Robotics by providing both broad and detailed perspectives on cutting-edge theories and developments in the field. This collection is designed to act as a single reference source on conceptual, methodological, technical, and organizational issues, as well as provide insight into emerging trends and future opportunities within the discipline.

Robotics: Concepts, Methodologies, Tools, and Applications is organized into six distinct sections that provide comprehensive coverage of important topics. The sections are (1) Fundamental Concepts and Theories, (2) Development and Design Methodologies, (3) Tools and Technologies, (4) Utilization and Application, (5) Organizational and Social Implications, and (6) Emerging Trends. The following paragraphs provide a summary of what readers may expect from this invaluable reference tool.

Section 1, "Fundamental Concepts and Theories," provides an overview of the subject by exploring several key topics and applications in the field of Robotics. The section begins with *History of Service Robots* by Zielinska Teresa, a chapter that brings together the current state of robotic assistive technologies with future trends in the field. In addition to service robotics, chapters in this section discuss computer vision technologies and applications (*3D Scene Capture and Analysis for Intelligent Robotics* by Ray Jarvis), artificial intelligence (*A Framework for Prototyping of Autonomous Multi-Robot Systems for Search, Rescue, and Reconnaissance* by Sedat Dogru, Sebahattin Topal, Aydan M. Erkmen, and Ismet Erkmen), and applications for education (*Educational Robotics Theories and Practice* by Amy Eguchi) and public libraries (*The Inevitability of Library Automation* by Edward Iglesias). In all, this section introduces the reader to some of the important ideas and current considerations in the research and development of robotic systems, concepts that will be explored in greater depth throughout the remaining sections.

Section 2, "Development and Design Methodologies," explores some of the fundamental properties of Robotics systems. The first few chapters build on the service applications described in Section One to include learning and reasoning tools, such as *Mission Planning of Mobile Robots and Manipulators for Service Applications* by Elias K. Xidias, Nikos A. Aspragathos, and Philip N. Azariadis and *Gesture Learning by Imitation Architecture for a Social Robot* by J. P. Bandera, J. A. Rodríguez, and A. Bandera. Subsequently, the section addresses the concept of swarm intelligence and interactions between robots in *Self Control and Server-Supervisory Control for Multiple Mobile Robots, and its Applicability to Intelligent DNC System* by F. Nagata, T. Yamashiro, N. Kitahara, A. Otsuka, K. Watanabe, and Maki K. Habib, as well as several other central chapters. Finally, the section concludes with two chapters on the

functional design of robots for particular applications: *Design and Operation of Two Service Robot Arms* by Jean-Pierre Gazeau and Saïd Zeghloul, and *Prototyping of Lunabotic Excavator Robotic System* by Nicolae Gari and Xingguo Xiong.

Section 3, "Tools and Technologies," bridges the gap between theory and practice with a discussion of recent development in tangible Robotics technologies. The opening chapters continue from the previous section by describing various robotic limbs and manipulators, such as *Portable Haptic Arm Exoskeleton* by Pierre Letier and André Preumont and *Medical Manipulators for Surgical Applications* by Xing-guang Duan, Xing-tao Wang, and Qiang Huang. Next, the section explores some potential applications for these technologies, with chapters such as *Agile Wheeled Mobile Robots for Service in Natural Environment* by Jean-Christophe Fauroux, Belhassen-Chedli Bouzgarrou, Nicolas Bouton, Philippe Vaslin, Roland Lenain, and Frédéric Chapelle and *Needle Insertion Force Modeling using Genetic Programming Polynomial Higher Order Neural Network* by Mehdi Fallahnezhad and Hashem Yousefi, among others. The closing chapters focus on robotic vision technologies, ending with *Visual Control of an Autonomous Indoor Robotic Blimp* by L. M. Alkurdi and R. B. Fisher, a chapter that transitions nicely into the next section and its discussion of robot applications in indoor environments.

Section 4, "Utilization and Application," describes some of the various uses for the technologies presented in the first three sections, further demonstrating the applicability of Robotics to other diverse fields and endeavors. The section begins with applications in restricted environments, such as homes and industrial infrastructure. Notably, *Study and Design of an Autonomous Mobile Robot Applied to Underwater Cleaning* by Lafaete Creomar Lima Junior, Armando Carlos de Pina Filho, and Aloísio Carlos de Pina and *Prototyping of Fully Autonomous Indoor Patrolling Mobile Robots* by Xiaojun Wu, Bingbing Liu, Jun-Hong Lee, Vikas Reddy, and Xi Zheng explore two such applications. Next, the following chapters expand upon the swarm intelligence concepts illustrated in Section Two, including *Safer and Faster Humanitarian Demining with Robots* by Emin Faruk Kececi. Additional applications can be found in the energy (*Mechatronics Technology for Solar Cells* by H. Henry Zhang, Danny Rodriguez, and Qiong Li) and agricultural (*Service Robots for Agriculture* by Andrea Manuello Bertetto) sectors, and the final chapters cover Medical Robotics, notably *Surgical Robots* by Tamás Haidegger and *Wearable Power Assist Robot Driven with Pneumatic Rubber Artificial Muscles* by Toshiro Noritsugu.

Section 5, "Organizational and Social Implications," moves away from the physical aspects of Robotics to explore the impact that these technologies have on society and human interaction. The section begins with chapters on rehabilitation and assistive technologies, including *Gait Rhythm of Parkinson's Disease Patients and an Interpersonal Synchrony Emulation System Based on Cooperative Gait* by Hirotaka Uchitomi, Kazuki Suzuki, Tatsunori Nishi, Michael J. Hove, Yoshihiro Miyake, Satoshi Orimo, and Yoshiaki Wada and *Interactive Games with Robotic and Augmented Reality Technology in Cognitive and Motor Rehabilitation* by Ana Belén Naranjo-Saucedo, Cristina Suárez-Mejías, Carlos L. Parra-Calderón, Ester González-Aguado, Frida Böckel-Martínez, Antoni Yuste-Marco, Pablo Bustos, Luis Manso, Pilar Bachiller, Sergi Plana, Jose M. Diaz, Ricardo Boniche, and Adriá Marco. The majority of the chapters in this section cover human-machine interaction and how modern technologies affect human identity. In particular, *Human-Friendly Mechatronics Systems with Functional Fluids and Elastomers* by Takehito Kikuchi evaluates safety concerns in human-machine coexistence, and *Just Doesn't Look Right* by Julie Carpenter describes how the design and appearance of a robot can affect the way it is perceived by its human counterparts. The section concludes with two chapters on Robotics education, a crucial first step in the development of new Robotics technologies.

Section 6, "Emerging Trends," completes this valuable reference source with insight into the most recent advances and future developments in Robotics technologies. The chapters in this section extrapolate on the concepts and applications discussed in previous sections, including robot vision (*Self-Calibration of Eye-to-Hand and Workspace for Mobile Service Robot* by Jwu-Sheng Hu and Yung-Jung Chang), navigation (*Collaborative Exploration Based on Simultaneous Localization and Mapping* by Domenec Puig), multi-robot systems (*Ad Hoc Communications for Wireless Robots in Indoor Environments* by Laura Victoria Escamilla Del Río and Juan Michel García Díaz), and human-computer interaction (*Understanding the Human-Machine Interface in a Time of Change* by Erica Orange), among others. The diverse natures of the chapters in this section are indicative of the variety of applications and benefits that Robotics technologies provide to enhance human lives. The final chapter, *A Neurorobotics Approach to Investigating Word Learning Behaviors* by Richard Veale effectively concludes this essential three-volume reference by exploring how a greater understanding of robots can help us to better understand ourselves and our environment.

As a comprehensive collection of research on current findings related to the development of interdisciplinary technologies, *Robotics: Concepts, Methodologies, Tools, and Applications* provides researchers, administrators, and all audiences with a complete understanding of the latest advances, applications, and concepts in Robotics. Although the primary organization of the contents in this multi-volume work is based on its six sections, offering a progression of coverage on the important concepts, methodologies, technologies, applications, social issues, and emerging trends, the reader can also identify specific content by utilizing the extensive indexing system found at the end of each volume. Given the vast number of issues concerning usage, successes and failures, policies, strategies, and applications of Robotics in countries around the world, *Robotics: Concepts, Methodologies, Tools, and Applications* addresses the demand for a resource that encompasses the most pertinent research on the technologies being employed to globally bolster the knowledge and implementation of Robotics.

Section 1
Fundamental Concepts and Theories

This section provides an overview of the subject by exploring several key topics and applications in the field of Robotics. As a discipline, Robotics is fairly young, but in our modern, technology-driven society, autonomous machines are increasingly imperative. Some of the topics illustrated in this section include service robots, object recognition, path detection, library automation, and others. In the opening 11 chapters of this extensive reference source, readers will obtain a clear understanding of the fundamental concepts and theories integral to the field of Robotics.

Chapter 1
History of Service Robots

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ABSTRACT

The short history of service robots with its precursors is given. Next, the definition of service robot is discussed and some statistical data is given. The described history of service robots covers the ancient period with robot precursors, the middle ages, and the period of industrial revolution. The representative examples of different kinds of service robots built in the twentieth century are given. The chapter is concluded with future trends.

BACKGROUND: WHAT IS A SERVICE ROBOT

Service robots have no strict officially accepted definition, they represent very different structures and abilities and are used in many different applications.

International Federation of Robotics (IFR) gives the following provisional definition: "A service robot is a robot which operates semi- or fully-autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations."

And it continues with this explanation:

With this definition, manipulating industrial robots could also be regarded as service robots, provided they are installed in non-manufacturing operations. Service robots may or may not be equipped with an arm structure as is the industrial robot. Often, but not always, the service robots are mobile. In some cases, service robots consist of a mobile platform on which one or several arms are attached and controlled in the same mode as the arms of the industrial robot.

By the end of 1990s, the International Service Robot Association (ISRA) issued following working definition of service robots: "Machines that sense, think, and act to benefit or extend human capabilities and to increase human productivity" (Pransky, 1996).

In general there exists no uniform robot categorisation. Here, we refer to the classification proposed in Zielinski (2010) where the robots are classified according to the type of acting environment.

- **Industrial robots** Are operating in a fully structured environment. For example, in the work cell all devices are strictly co-operating, so it is sufficient that the robot control is position based, and therefore not many external sensors are needed.
- **Personal service** Robots are operating in a quasi-structural environment, created by man for its own purposes. It means that the surrounding is not exactly adjusted to the needs of the performed job (e.g., regular home, waiting hall, office, restaurant).
- **Field robots** Work for the group of anonymous recipients in the natural environment which is fully unstructured, for example: the forest, sky space, sea bottom, ruins, mountains. Field robots represent the category of professional service robots.

Personal and field robots are combined in one group called *service robots*. The actions of service robots depend on information gathered by external sensors.

With the fast development of robotics and the variety of robots, the conclusion formulated by Joseph Engelberger—the "father" of robotics—is very proper: "I can't define a robot, but I know one when I see one."

Joseph Engelberger predicted that service robots would one day become the largest class of robot applications, outnumbering the industrial uses by several times; this is becoming a fact.

The idea of helping the human in heavy or repetitive work by artificial means has been observed since the beginning of humanity. Thus, tools and machines were conceived, built and used as intermediate solutions with increasing performances over the time.

It is difficult to specify when the first service robots appeared. Machines helping or entertaining the human can be treated as its precursors.

The first robots resembling humanoids were built in the beginning of the twentieth century for exhibitions and entertainment purposes. They are precursors of service robots and with this point of view the history of service robots is older than the history of industrial robots which started in 1950s.

The first helpmate indoor mobile robots appeared in the 1980s.

Currently, service robots are built for variety of applications, including: housekeeping and cleaning tasks, edutainment, inspection, rehabilitation and medical applications, surveillance, guidance and office works, agriculture, construction works, fire fighting, demining tasks, palletising, handling and picking goods, and search and rescue missions. The number of applications expands over the years.

Taking into account the type of performed task, the following four categories of service robots can be listed (Zielinski, 2010):

- Professional service providers (acting on the ground, in offices, in hospitals),
- Domestic service robots (helping in personal works, operating in the house, robots for entertainment, and education),
- Security robots (working for defence, safety, and rescue), and
- Space robots (working on space and doing planet exploration).

Soon service robots ("serving us" robots) will have millions of end-users in houses, hospitals, restaurants, offices, airports, etc.

SOME PAST AND RECENT PROGNOSES

In year 1989, Joseph Engelberger issued the book *Robotics in Service* (Engelberger, 1989) where he forecasted coming boom of service robots.

According to the International Federation of Robotics Statistical Department (IFR Statistical Department, 2010) through the year 2010 about 77 000 service robots were sold worldwide. The majority of robots were for military or agricultural purposes: about 30% of those were for military application, and 25% were for agriculture (milking robots). The others were as follows: cleaning robots: 8%, medical robots: 8%, underwater robots: 7%., construction robots: 6%, demolition robots: 6%, logistic system robots: 5%, and rescue and security: 4%. It is expected that in the near future the sales of personal (household and entertainment) robots will increase the most (see Figure 1).

An interesting overview of robotics development can be found in publications Ceccarelli (1998, 2001). The future of robotics is seen in low cost and easy operated systems, and in in-novative solutions for new applications (Ceccarelli, 1998).

Table 1 presents the classification of current robot applications and forecasts for the future. It is expected that the robots will gain more autonomy and will act independently of humans.

HISTORY OF SERVICE ROBOTS

Precursors

The idea of the artificial devices performing some tasks appeared a long time ago. According to the books of the *Iliad*, written by Homer (8 BC), one of the Greek gods built different artificial servants. Some of them were human-like. In Ancient Egypt artificial devices were used in the form of temple statues of gods operated by ropes. In his *Politics*, Aristotle stated that slavery will vanish when artificial tools are introduced performing autonomously the useful work. This brings the concept of the service robot.

Figure 1. Forecast of household and entertainment robots development (according to IFR Statistical Department, 2010)
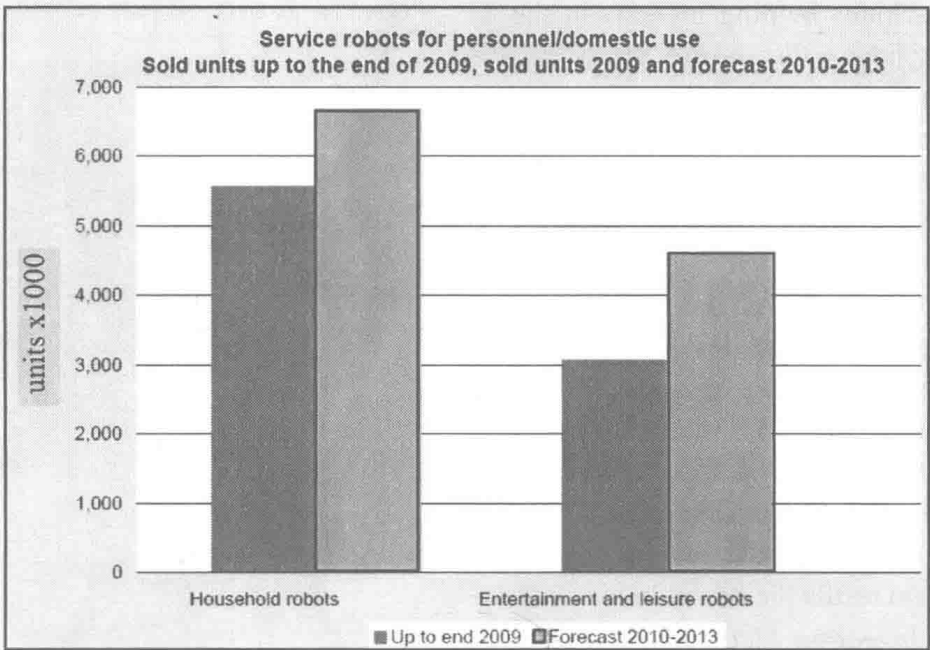
Table 1. Applications of service robots: current status and development prognoses

Robot category	Current applications	Expected application in coming years	Expected application in longer perspective
Professional service providers	Semi-autonomous servicing robots (in that tele-manipulators and surgery robots)	Autonomous assistants	Fully skilled workers (in that autonomous medical care takers)
Domestic service robots	Single task semi-autonomous devices	Autonomous domestic "tools"	Skilled home assistants (children and elderly care takers)
Security robots	UAV's, UGV's	Non-autonomous combats	Robotic squadrons (e.g. micro-robots, robots with swarm intelligence)
Space robots	Semi-autonomous servicing robots	Autonomous servicing	Autonomous space exploration

The physical roots of service robots can seen in ancient "robotics" theatres. The engineering of theatre machines was persistent in antiquity in Greece and in the Roman Empire. Greeks reached highs in knowledge even in technical fields. An emblematic example is the school of Alexandria where since the third century BC there was an intense activity in teaching and research on automatic devices. Hero of Alexandra's (the first century AD) *Treatise on Hydraulics, Treatise on Pneumatics,* and *Treatise on Mechanics* was the precursor of entertainment robots, due to his theatres with moving figures (Rosheim, 1994).

Greek culture evolved and circulated when combined with Roman technology. The Romans created some machines helping humans in the work. *Marcus Vitruvius Pollio* (born c. 80–70 BC) Roman writer, architect, and engineer in his treatise, *De Architectura* (*On Architecture*) described different machines helping human such as hoists, cranes, and pulleys, as well as war machines such as catapults and ballistae.

In the twelfth century AD Badi'as-Zaman Isma'il bin ar-Razzaz al-Jazari designed a figure which upon manual emptying of a water basin automatically filled it again with water (Rosheim, 1994) (Figure 2). It features a male humanoid automaton standing by a basin filled with water. When the user pulls the lever, the water drains and the male automaton refills the basin. In his *Book of Knowledge of Ingenious Mechanical Devices*

(1206) he described fifty mechanical devices with instructions on how to build them. His famous "magic" water clock was decorated with many moving figures. al-Jazari's works reveal an interest not only in dramatic illusion, but in manipulating the environment for human comfort. He was fascinated by practical applications. This was the key element that was missing in earlier Greek and Roman works. Therefore, al-Jazari must be recognised as one of the fathers of service robots.

The works dated to the eighteenth century can be interpreted as precursors of entertainment robots.

Figure 2. Jazari's figure serving the water

Figure 3. The dolls designed by Pierre Jaquet-Droz and Henri Jaquet-Droz: piano player (left), writer (right)

An impressing example of precise and skilful mechanical dolls (Figure 3) are the mechanisms built in the eighteenth century by Swiss watchmakers: Pierre Jaquet-Droz, his son Henri Jaquet-Droz, Jean Frederic Leschat, and Henri Millardet. Those dolls were programmable by exchange of pegs pushing cams. The dolls were capable of drawing, writing, or playing piano with very precise motion of their fingers. As they were programmed, what was written, drawn, or played could be changed.

A sketch of a mechanical knight made by Leonardo da Vinci in 1495, which could sit up and move its arms and legs, is considered the first plan of a humanoid robot.

Table 2 summarizes most of the known challenges in making the fundaments for service robots (see also Figures 4, 5, and 6).

Early Robots and Helpmates

The twentieth century was marked by an extensive development of diverse robots; this was especially visible after the 1950s, after introducing computer control. The invention of the electric motor which was half a century earlier created the first significant stimuli for robotics.

In the first 40 years of the twentieth century several humanoidal robots were designed. Probably one of the first more advanced prototypes was humanoid Televox invented and patented by R. J. Wensley (USA) (Figure 7). The patent (submitted in 1923) covered the supervisory control system applied in Televox which was shown in the year 1927. The robot responded by simple actions to tuned tones.

Figure 4. Selected works of Hero from Alexandria: Figures' motions are powered by water or steam water
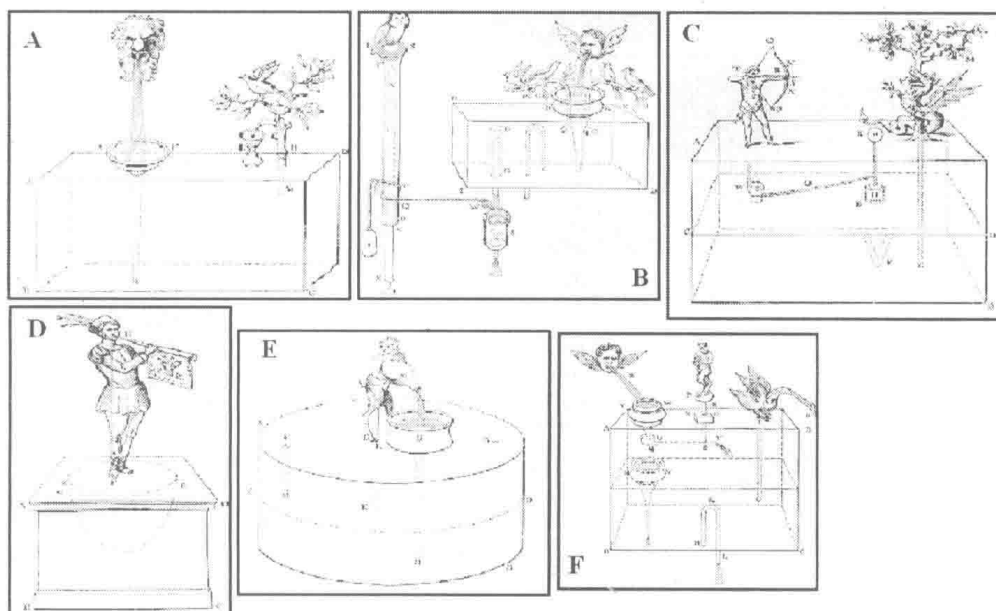
Table 2. Precursors of service robots

Period	Type of the device	Comment	Region/Inventor or Producer
5th-1st c. BC	Figures (god statues) with parts moved by humans	Figures with moving parts dragged by ropes	Egypt, Greece, Alexandria /persons serving the temples
3rd c. BC	Figures animated by water or steam water	The pneumatics laws were discovered and used for motion animation	Alexandria/Ctesibius
3rd c. BC	"Mechanical" orchestra. Figures were probably animated by ropes	Orchestra owned by emperor Qin Shihunagdi. No details are known. Qin Shihuangdi was suffering melancholy and, by the end of his life, ordered the destruction of all books.	China/not known
2nd c. BC	Pneumatically powered figures	Continuator of Phylo's work	Byzantium/Phylo of Byzantium
1st c. AD	Theatres of moving figures	Roots of entertainment robots (Figure 4) Designer of mechanical hammer (Figure 5)	Alexandria/Hero of Alexandria
3rd c. AD	Walking machine Mu Niu Liu Ma (precursor of walking robot)	According to the descriptions it was an animal shaped wheelbarrow with legs transferred in sequence observed in horses slow walk. It was used for transportation.	The construction was supervised by Zhu Ge-Liang/China
11th c. AD	Su Sung Tower	Clock Tower with water driven escapement (Figure 6)	China/Su Sung
12th c. AD	Early "programmable" automatons, in that "robotic" hand	First complicated mechanical devices with many moving parts	Turkey/Badi'as-Zaman Isma'il bin ar-Razzaz al-Jazari
15th-16th c. AD	Moving platforms carrying the figures		Italy/Leanardo da Vinci
16th-17th c. AD	Dolls dancing and/or playing diverse musical instruments (automatons)	Hans Bullmann (Germany) is often listed as the first creator of android in the human form (1525)	Italy, Germany, Austria/Juanelo Torreano, Turriano from Cremone, Hans Bullmann, Christoph Margraf
17th c. AD	Different automatons	Complex automations, in that machine animating a whole army in fight.	France/Christiaan Huygens
18th c. AD	Digesting duck, flute player imitating the briding	First automations exhibiting the functions of biological organisms	France/Jacques de Vaucanson
18th c. AD	Programmable automatons; dolls writing different words, playing the piano	The piano playing doll hand was moving the fingers very fast, the doll played music like a real human	Pierre Jaquet-Droz, and his son Henri Jaquet-Droz/Swiss
17th-19th c. AD	Steam engines with legs (precursors of walking robots)	Probably the first walking devices with on-board actuation	England/T. Brunton, D. Gordon
19th c. AD	Feet Walking Machine (Stopochodjaszczaja Machina)	The proportions were carefully evaluated; the leg end transfer sequence and leg-end trajectories were such as observed in animals.	Russia/P. L. Tchebychev
19th c. AD	Karakuri: mechanical toys serving the tea, shooting the arrows, or painting		Japan/Hishashige Tanaka

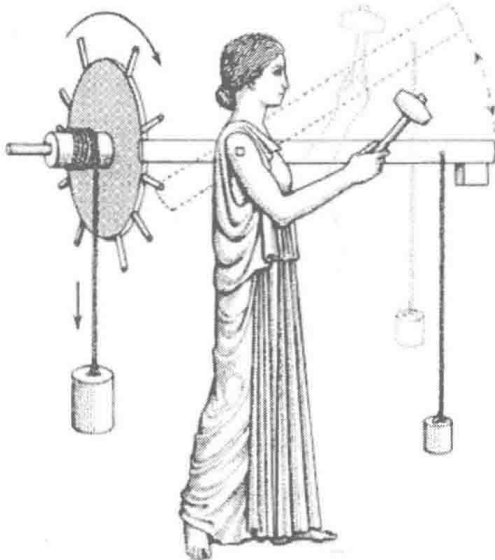*Figure 5. Mechanical hammer by Hero of Alexandria*

Figure 6. The oldest known illustration of an endless power-transmitting chain: The "celestial ladder." Su Sung applied it in his clock tower, and described it in his book Xinyi Xiangfayao (1092).
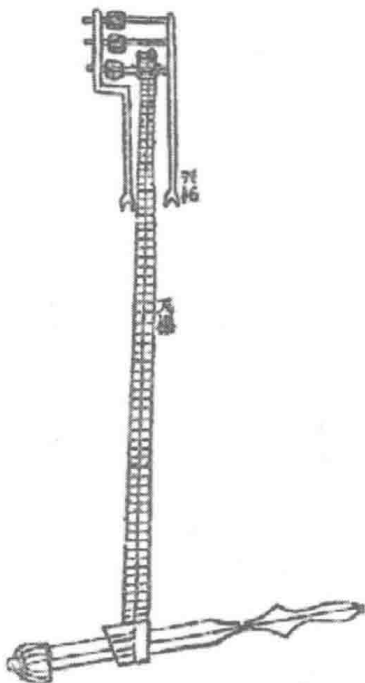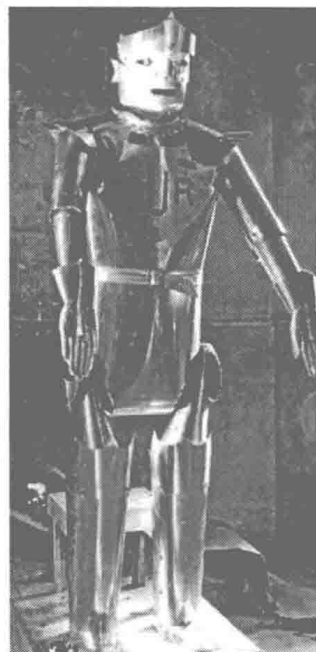

Figure 7. Televox robot with his constructor R. J. Wensley

Figure 8. Robot named Eric RUR (RUR comes from Carel Capek play RUR–Rossum's Universal Robot, where the term robot was created) (Chronicle Telegram, 26 Nov 1928, p.14)

In 1928, the Model Engineers Society exhibited in London an electrically actuated humanoidal robot Eric designed by W. H. Richards (Figure 8).

The dog—Philidog (designed by M. Piraux from the Philips company) appeared during the Paris International Radio Exhibition (1929). The dog "followed the movements of light, but when the lamp was put too close to its nose sensor... it would become annoyed and start to bark!" For the 1939 New York World's Fair, a walking human-shape robot ELECTRO and his dog SPARKO were built. ELECTRO and SPARKO were designed by B. Barnett and produced by Westinghouse Electric Corporation (Figure 9). ELECTRO was capable of performing over 25 movements and responded to commands spoken into a microphone. SPARKO was the first robotic victim of the car accident. Just before the exhibition opening, SPARKO went out of the building, attracted by the headlights of an automobile, and was destroyed.

In 1948 the first robots with biological behaviours—Elsie and Elmer—were created by William Grey Walter. Those tortoises could dance with each other due to attraction with a light source attached to each robot; it was without any specific perception of the other robot and with no special social rules implemented.

Thirty years after creating Unimation—the first company producing industrial robots—in 1954, J. Engelberger founded Transitions Research

Figure 9. The cover page of Radio-Craft magazine (1939) describing ELECTRO robot
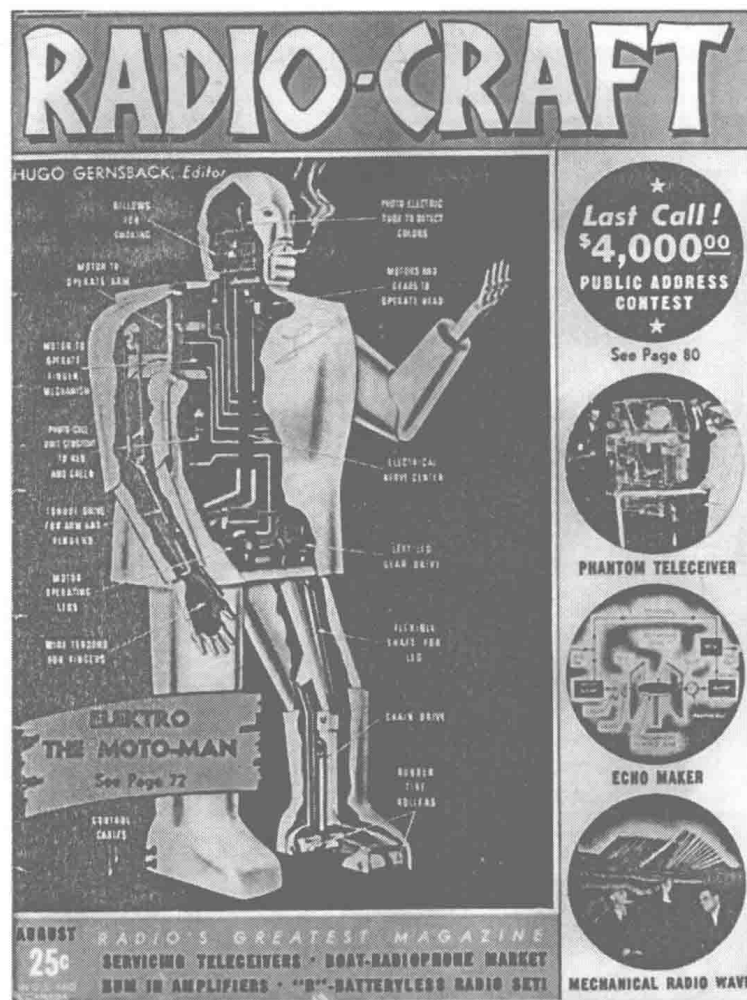
Corporation in 1984, which became HelpMate Robotics Inc. Since the beginning, this corporation focused on mobile robots equipped with sensors, servicing humans, and especially robots for elderly care and for medical applications.

Service robots are also developed for dangerous, impossible, or unacceptable jobs. Those robots are mobile platforms, manipulators, tele-manipulators, or mobile robots with manipulation abilities.

In 1987, Hughes Research Laboratories demonstrated an autonomous mobile robot navigating in cross-country environment. From 1990-1994, Carnegie Mellon University developed Dane I and Dante II—robots for volcano exploration. In 1997 NASA sent the mobile robot Sojourner to Mars. The robot performed its mission successfully.

Fast progress in sensing technologies, development of control equipment, improvements of actuators and power supplies in the 1980s and early 1990s resulted in many robot projects dedicated for new non-manufacturing applications (Figure 10).

The specific types of service robots are UAVs and AUVs. The precursors of UAVs (Unmanned Aerial Vehicles) are flying autonomous bombs (V-1, V-2) tested during the second World War.

Till our days a variety of UAV's with different sizes, abilities, and ranges were designed. They are used for military and civilian missions like search and rescue, and monitoring the environment, or checking the state of pipelines (Figure 11).

Autonomous Underwater Vehicles (AUVs) known also as Unmanned Undersea Vehicles (UUVs) are the robots acting in water (Figure 12). They are used to make maps of the seafloor, to monitor the underwater pipelines, and to perform military or research missions.

A large group of service robots are the surveillance, patrol, and security mobile robots. Military robots similar to UAVs have their roots in the Second World War with Goliaths tracked mines (Germany) or tele-tanks (Russia). Those robots named UGVs (Unmanned Ground Vehicles) are autonomous and are equipped in different sensors, tools, or are armed (Figure 13).

Today

In 1962, Russia was elaborated a mobile robot named Sepulka, which was designed as a tour guide (Figure 14). This robot started its work in

Figure 10. Service robots development