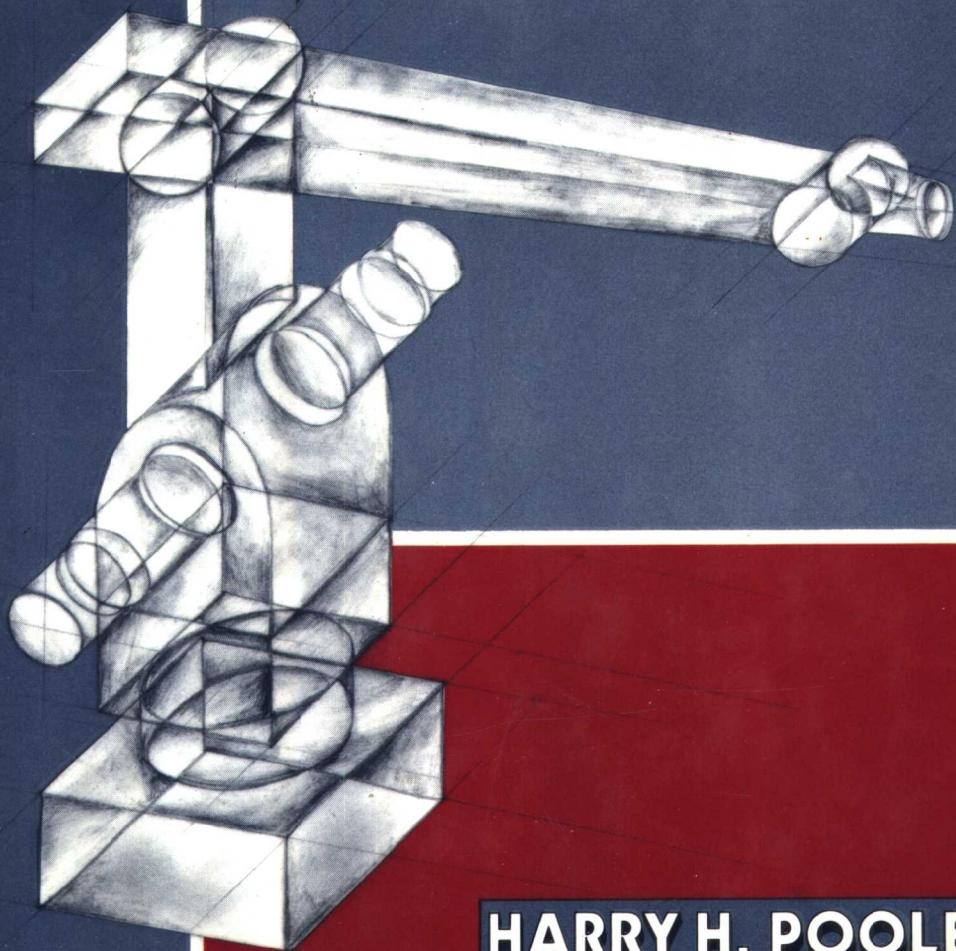


FUNDAMENTALS **of** **ROBOTICS** **ENGINEERING**



HARRY H. POOLE

FUNDAMENTALS OF ROBOTICS ENGINEERING

Harry H. Poole

Poole Associates



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PREFACE

Robotics engineering has progressed from an infant industry in 1961 to one including over 500 robot and allied firms around the world in 1989. During this growth period, many robotics books have been published, some of which have served as industry standards. Until recently, the design of robotics systems has been primarily the responsibility of the mechanical engineer, and their application in factories has been the responsibility of the manufacturing engineer. Few robotics books address the many systems issues facing electronics engineers or computer programmers.

The mid-1980s witnessed a major change in the robotics field. The development of advanced sensor systems (particularly vision), improvements in the intelligence area, and the desire to integrate groups of robots working together in local work cells or in factory-wide systems have greatly increased the participation of electronics engineers and computer programmers. Further, as robots gain mobility, they are being used in completely new areas, such as construction, firefighting, and underwater exploration, and the need for computers and smart sensors has increased.

Fundamentals of Robotics Engineering is aimed at the practicing electrical engineer or computer analyst who needs to review the fundamentals of engineering as applied to robotics and to understand the impact on system design caused by constraints unique to robotics. Because there are many good texts covering mechanical engineering topics, this book is limited to an overview of those topics and the effects they have on electrical design and system programs.

The text also covers related areas such as sensor subsystems and robot communication protocols. It discusses robot standards and describes representative robotic applications and the impact they have on system design requirements. It provides much needed information in the areas of ultrasonics and mobile robots.

The book extrapolates into future robotics techniques and applications by reviewing current work in research and university laboratories around the country and, to a lesser extent, advanced applications in Europe and Japan. New techniques, new applications, and trends are also covered. By presenting information about some work still in the research stage or only being applied in other countries at the present time, *Fundamentals of Robotics Engineering* should help engineers to be up to date in this important technological area.

The book concludes with a series of appendixes including a partial list of robotics manufacturers, major university research laboratories, international robotics organizations, and a glossary of robotics terms.

Any book can only be of finite size. In the number of pages that an author has to explain a subject, he or she has a number of difficult choices to make. Should the book approach the subject from a theoretical or a practical viewpoint? Should the book treat a few topics in depth or should it treat many topics in less detail? Should actual company products be described, or should more general approaches be covered?

Fundamentals of Robotics Engineering has been written with the needs of the robotics system designer in mind. It can also be used to supplement undergraduate and graduate courses in robotics. Therefore the practical approaches available in the marketplace are well covered, and the many alternatives that a system designer can select from are included. In addition, other promising techniques, although perhaps not yet commercially available, are also discussed. As such, the approach taken in this book is primarily a more general and practical one, although theory is also well covered.

ACKNOWLEDGMENTS

Any book is the product of the efforts of many individuals and the cooperation of many companies. It is, unfortunately, impossible to list everyone who has contributed. However, the author would like to thank certain individuals without whose able assistance this book could not have been completed.

Most of the art work was supplied by Paula Bushee and James Hess. Douglas Poole helped to obtain photographs. Carolyn Turcio provided some of the text for chapter 11 and several of the drawings. Of prime importance was the assistance of my wife, Marjorie Poole, in helping me meet the many deadlines that authors are faced with. To these individuals and to the countless others at firms around the world who supplied information and pictures, I give my heartfelt thanks.

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PART I

AN OVERVIEW OF ROBOTICS

Robotics is the science or technology that deals with robots. Defining a *robot*, however, is not easy. The public image of a robot, produced through myriad motion pictures and books that give them human characteristics and apparently superhuman intelligence is partially responsible for the difficulty. A constantly changing technology, which provides robots with increasing levels of abilities, also contributes to the problem. For example, in 1987 a California doctor demonstrated a robot at Robots 11 that can assist surgeons during brain biopsies. It is, therefore, hard to define exactly what potential abilities may be found in robots and which applications are realistic and practical. It is also difficult to keep various industry standard definitions up to date, as most continue to stress one part of a robot—its manipulator.

Because it is an engineering systems book on robotics, this book attempts to cover enough technology to describe what the robot does today and what it can be built to do tomorrow. Chapter 1 begins with the history of robotics to develop a working definition of robots and to provide a sound background. It then discusses the growth of the robotics industry and introduces robot engineering. Chapter 2 examines and classifies current robots, using six different criteria, providing necessary points of reference for the balance of the book.

INTRODUCTION

As part of a 1983 seminar on robot sensing and intelligence,¹ Dr. Antal Bejczy of the Jet Propulsion Lab gave the following definition of robots: “There are three parts to the technical definition of robots. First, robots are general purpose mechanical machines. Second, they are programmable to perform a variety of work within their mechanical capabilities. Third, they operate automatically.” Dr. Bejczy also stated that automation is the key for advancing the state of the art in robotics. This useful definition thus combines mechanical engineering, computer programming, and electrical engineering. Taking the lead from Dr. Bejczy, this book concentrates on the second and third parts of his definition, the programming and automation of today’s robots.

1.1 BRIEF HISTORY OF ROBOTICS

Stories of mechanical men, predecessors of the robot C3PO of *Star Wars* fame, have been around since the days of Greek myths, and motion pictures have been showing fictional robots from the earliest film days (Georges Méliès, the French pioneer filmmaker, made *The Clown and the Automaton* in 1897). Over the last several centuries, skilled craftsmen developed early versions of mechanical robots. Although the word *robot* was not coined until the twentieth century, mechanical humanoid robots, called *automata*, were built as early as the 1500s, when moving figures were used to perform useful work, such as striking a bell on the hour.

By the 1700s, clever inventors had added many advanced capabilities to these devices, culminating perhaps in the automata developed by Pierre



Figure 1-1. Early automaton. (Courtesy of Musée d'Art et d'Histoire, Neuchâtel, Switzerland)

Jacquet-Droz, a creator of puppets. One of these devices, named “The Scribe” (or writer), can still be seen at work in a Neuchâtel (Switzerland) museum. It is a well-constructed model of a young man seated at a desk (Fig. 1-1). When activated, the automaton dips its quill pen into an inkwell and writes previously selected text of up to 40 letters in length. What makes this device of particular interest to the robotics engineer is that it is programmable. With appropriate changes of cams and levers (similar to changing instructions), the automaton can be made to write any text.

Although numerous automatons were built over the years, they were of interest primarily as entertaining novelties, and, unfortunately, their technology was not applied to industry. Not until the mid-1950s was robotic technology adapted by industry to handle the more dangerous manufacturing tasks.

The term *robot* was first used in two plays written by the Czech author Karel Capek. *Opilec* was the first, written in 1917. It is less well known than his later masterpiece *R.U.R.*, an abbreviation of Rossum’s Universal Robots. An English version of this latter work is available.²

R.U.R. was first produced in Prague in 1921, and then attained worldwide attention by being presented in New York in 1922. The play developed the concept of small, manlike creatures obeying their master’s instructions. The term *robot*, derived from the Czech word *robota*, means forced labor or compulsory service, and was the name given to these creatures. Subsequently, films and science fiction further publicized robots.

During the Second World War, the meaning of robot was extended to include an automatic pilot, such as found in robot bombs. This was also the period of two related steps—the development of the computer and the use of the first remote manipulators, now known as *teleoperated robots* or *telechirs*. Hence, robot technology evolution dates from the Second World War. Further steps in the development cycle included servo systems, numerical control, process control, industrial robots, and, finally, advanced robots. In 1954, the first industrial robot was built, and the first two industrial robot patents were applied for. It was the dawn of the robotics age.

A radiator manufacturing company, in 1954, asked Planet Corporation of Lansing, Michigan, to design a system to handle hot castings while they were water quenched and then placed on a press die. Planet, which took three years to solve the problem, demonstrated its robot technology at the International Trade Fair on Automation in Stockholm in 1957, after an invitation from the U.S. Department of Commerce. Planet named the robot Planobot, and it was publicized as the first industrial robot. Planobot (Fig. 1-2) was powered hydraulically and controlled through an electronic sequencer, going through a maximum of 25 steps to carry out a task. With five degrees of freedom, linear and rotary joint action, and an ability to be easily modified for changes in the production run, this model was a forerunner of the loading and unloading robots later developed successfully by Unimation.

During 1954, two robotic patents were applied for. In March, British inven-

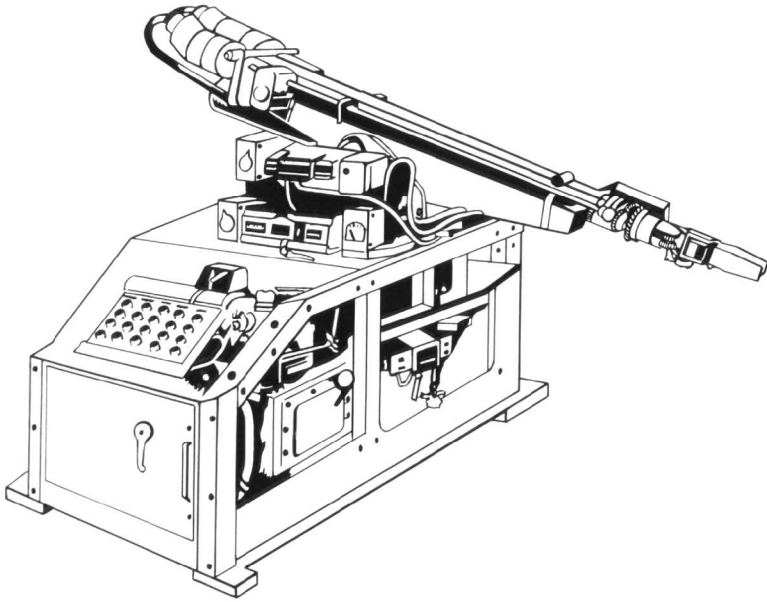


Figure 1-2. First industrial robot. (Courtesy of Carolyn Turcio)

tor Cyril W. Kenward applied for a British patent. The patent, issued in 1957 as number 781465, is titled *Manipulating Apparatus*. Kenward's device was a two-armed manipulator with four degrees of freedom moving in a Cartesian coordinate system. Two months later, American inventor George C. Davol applied for a patent. Davol's patent, titled *Programmed Article Transfer*, was granted in 1961 and served as the impetus behind Unimation. Founded in 1958, Unimation was the first company to specialize in robotics. The company name is a contraction of "universal automation." Another entry into the robotics field during 1958 was AMF, which began developing its Versatron robot. Versatron was subsequently made a division of Prab Robots.

The first Unimation industrial robots were built in 1961 and, like Planet's robot, were used in the unpleasant and dangerous task of loading and unloading die casting machines. Their first robot, originally delivered to a General Motors automobile plant in New Jersey, has been moved to an exhibit at the Smithsonian Institution in Washington.

After a slow start, interest began to build in 1965 as many companies from different nations entered the field. The first robots were pick-and-place robots with little intelligence, but they were very reliable, even under poor working conditions. In 1966 a Norwegian agricultural machinery firm (Trallfa), built a robot to paint wheelbarrows. In 1969, Unimation introduced the first spot-

welding robot, and by 1972 Unimation was offering three series of robots. By the end of that year, *Fortune* magazine indicated that 500 robots had been installed in factories.

Universities were also becoming involved in robotics research. Progress in robot mobility, vision systems, and artificial intelligence was being made at Stanford Research Institute (now SRI International) in the late 1960s. The first mobile robot was developed at Stanford under a Department of Defense grant. Called Shakey because of the intermittent manner in which it moved and the vibration of the vision camera support structure, the robot showed an amazing degree of intelligence for its time. In one famous task, Shakey was given the job of reaching an object placed on a platform. The robot was on wheels, so it could not climb the platform. Looking around, Shakey spotted a ramp. It pushed the ramp to the platform, propelled itself up the ramp, and reached the object.

Another pioneer, MIT, also had robotics projects underway as part of its work in artificial intelligence. Particularly significant was MIT's development of a mechanical hand, suggested by a thesis in 1961, and of early robot languages, such as MHI and MINI.

Under license from Unimation, Kawasaki Heavy Industries in 1969 developed the first industrial robot in Japan. Other Japanese firms saw the potential of robots in industry and, in 1971, formed the Japanese Industrial Robot Association, four years ahead of its counterpart in the United States. Japan has pursued the robotics area so aggressively that they now lead all other countries in robotics, both as manufacturers and users. They also lead the world in several areas of robot technology.

The first adaptive robot, built in 1970 by the Electric-Technical Laboratory, a Division of the Japanese Ministry of International Trade and Development (MITI), had a vision system that could distinguish nine colors. The robot could also detect and correct errors in its actions. MITI is still a leader in robotics research.

France joined the international push into robotics during the early 1970s when it set up research and development facilities under government support. The USSR developed its first robot during 1971 and 1972. Other European countries, including West Germany, Sweden, and Italy, also became active participants in the industry during the early 1970s.

Early robots were hydraulic-based. The first all-electric model was built in 1973 by ASEA, a Swedish firm. In that year the concept of revolute joint construction was introduced by Cincinnati Milacron, and the Trallfa robot from Norway became the first continuous-path robot.

The first multiarmed, overhead robot (*Sigma*) was built by Olivetti in 1975. In 1978, Unimation introduced a smaller robot, the PUMA (programmable universal machine of assembly). A later model (the PUMA 700) is shown in Figure 1-3. This robot was designed to handle small parts and is still in



Figure 1-3. PUMA robot. (Courtesy of Unimation, Inc.)

widespread use. By 1980, Unimation was shipping 600 robots a year, about half of the robots built in the United States.

The next big step forward in robot technology came from the Japanese in 1979, with the selective compliance assembly robot arm (SCARA). Developed at Yamanashi University, this robot combined inflexible motion in the vertical plane with compliance, or flexible positioning in the horizontal plane, allow-