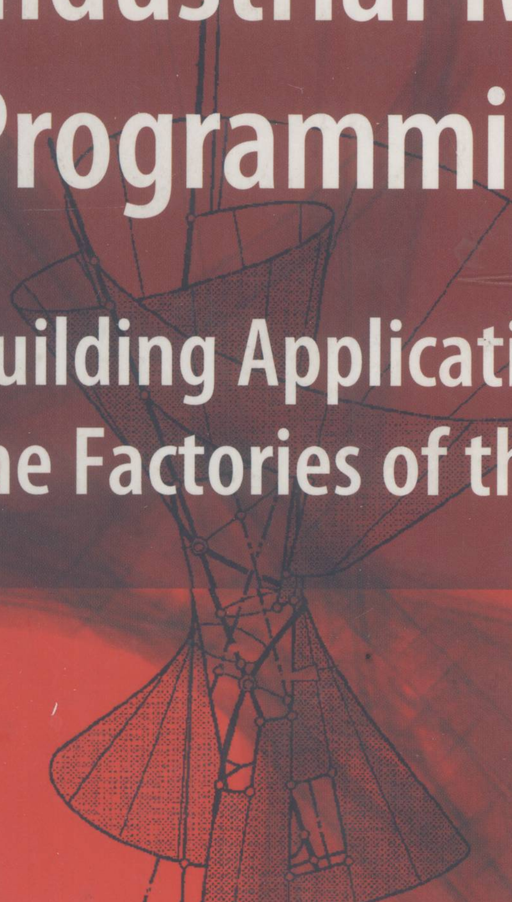
J. Norberto Pires

Industrial Robots Programming

Building Applications for the Factories of the Future



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INDUSTRIAL ROBOTS PROGRAMMING:
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INDUSTRIAL ROBOTS PROGRAMMING:
BUILDING APPLICATIONS FOR THE FACTORIES OF THE FUTURE

Dedicated to the memory of my father Joaquim
and to Dina, Rita, Beatriz and Olímpia.

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Foreword

Robots have traditionally been used to work in industrial environments, as they constitute the most flexible existing automation technology. In the recent years, manufacturing systems are becoming more autonomous requiring less operator intervention and a higher degree of customization and reconfigurability for disparate applications. In this scenario, robot programming is a key factor toward building the applications for the factories of the future.

This book by J. Norberto Pires constitutes a unique and authoritative reference in our professional field, as one of the very few books written by an academic with a strong industrial cut. The focus is on the software interfaces enabling humans and machines to effectively cooperate on the shopfloor. Several sensors and controllers are analyzed in detail, leading to the realization of interface devices using e.g. speech recognition and CAD models, and their versatility for a number of industrial manufacturing systems is enlightened.

Easy to read, rich in worked out examples and case studies, the book is complemented with additional experimental material available on a web site, including code and multimedia files, which the author promises to update regularly.

It is my conviction the book will be appreciated by a wide readership, ranging from technical engineers wishing to learn the foundations of industrial robotics to scholars and researchers wishing to understand the needs and the potential of a new generation of advanced industrial robots to be developed in the next decade.

Bruno Siciliano
Professor of Control and Robotics at the University of Naples
President-Elect of the IEEE Robotics and Automation Society

Preface

A scientific and technical book is a starting point. A source of information for people browsing for details, a guide for others trying to build similar or related solutions, or a source of inspiration for yet others wondering about how things work.

This book was written by an engineer and university professor which has been active in the field of industrial robotics since 1994. It was planned, designed and built to serve engineers looking for better and more efficient systems, but also to serve academic readers interested in the robotics area. The book focus mainly on industrial robot programming in the beginning of the twentieth first century, namely on the important issues related with designing, building and operating flexible and agile robotic systems. It explores in detail the issue of software interfaces, but also input/output devices and several industrial and laboratory examples. In fact, the book uses several types of fully worked out examples to illustrate and clarify concepts and ideas, enabling the reader to see them working and even to test some of them. Most of the experimental material used in this book can be obtained from:

http://robotics.dem.uc.pt/indrobprog

This site will be updated regularly by the author constituting a source of information, code and multimedia files which complement the contents of the book.

Finally, the author wants to thank deeply to all the persons that contributed to this book, namely all his undergraduate and graduate students, specially his Ph.D. students Tiago Godinho and Germano Veiga, and his M.Sc. student Ricardo Araújo for their help and support in building and testing some of the solutions presented in the book.

J. Norberto Pires, Coimbra, Portugal, 2006

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Introduction to the Industrial Robotics World

1.1 Introduction

Robotics is a subject that leaves nobody indifferent. No matter if they are used to work in industry or at our homes, mimic some of the human capabilities, or used to access dangerous environments, launched to space, or simply used to play with, robots are always a source of interest and admiration. Here the focus is in robots used to work on industrial environments [1], i.e., robots built to substitute man on certain industrial manufacturing tasks being a mechatronic coworker for humans.

In fact, actual manufacturing setups rely increasingly on technology. It is common to have all sources of equipment on the shop floor commanded by industrial computers or PLCs connected by an industrial network to other factory resources. Also, manufacturing systems are becoming more autonomous, requiring less operator intervention in daily operations. This is a consequence of today's market conditions, characterized by global competition, a strong pressure for better quality at lower prices, and products defined in part by the end-user. This means producing in small batches, never risking long stocks, and working to satisfy existing customer orders. Consequently, concepts like flexibility and agility are fundamental in actual manufacturing plants, requiring much more from the systems used on the shop floor. Flexible manufacturing systems take advantage of being composed by programmable equipment to implement most of its characteristics, which are supported by reconfigurable mechanical parts.

Industrial robots are good examples of flexible manufacturing systems. Using robots in actual manufacturing platforms is, therefore, a decision to improve flexibility and to increase the agility of the manufacturing process. If the manufacturing processes are complex, with a low cycle time, and have a lot of parameterization due to the diversity of products, then using robots is the correct decision, although it isn't enough for a complete solution. In fact, engineers need to integrate other technologies with the objective of extracting from robots the flexibility they can offer. That means using computers for controlling and supervising manufacturing systems, industrial networks, and distributed software architectures [2,3]. It also means designing application software that is really distributed on the shop floor, taking advantage of the flexibility installed by using programmable equipment. Finally, it means taking special care of the human-machine interfaces (HMI), i.e., the devices, interfaces, and systems that enable humans and machines to cooperate on the shop floor as coworkers, taking advantage of each other's capabilities.

1.2 A Brief History of the Industrial Robot

The word "*robot*" comes from the Czech "*robota*" which means tireless work It was first used in 1921 by the novelist *Karel Capek* in his novel "*Rossum's Universal Robots*". Capek's robots (Figure 1.1) are tireless working machines that looked like humans and had advanced capabilities even when compared with actual robots. The fantasy associated with robotics offered by science fiction movies, and printed and animated cartoons is so far from reality that actual industrial robots seem primitive compared with the likes of *C3PO* and *R2-D2* (from the movie *Star Wars*), *Cyberdyne T1000* (from the movie *Terminator II*) *Bishop* (from the movie *Alien II*) and *Sonny* (from the movie *I Robot*), for example.

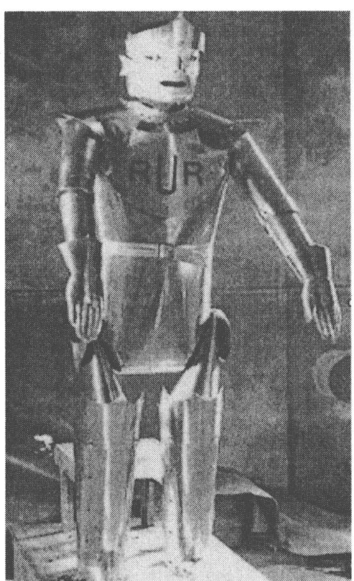

Figure 1.1 A robot from *Karel Capek's* novel "*Rossum's Universal Robots*"

But robotics was a special concern of the most brilliant minds of our common history, since many of them took time to imagine, design, and build machines that could mimic some human capabilities. It is one of the biggest dreams of man, to build obedient and tireless machines, capable of doing man's boring and repetitive work; an idea very well explained by *Nicola Tesla* in his diary [4]:

> *"... I conceived the idea of constructing an automaton which would mechanically represent me, and which would respond, as I do myself, but, of course, in a much more primitive manner, to external influences. Such an automaton evidently had to have motive power, organs for locomotion, directive organs, and one or more sensitive organs so adapted as to be excited by external stimuli ...".*

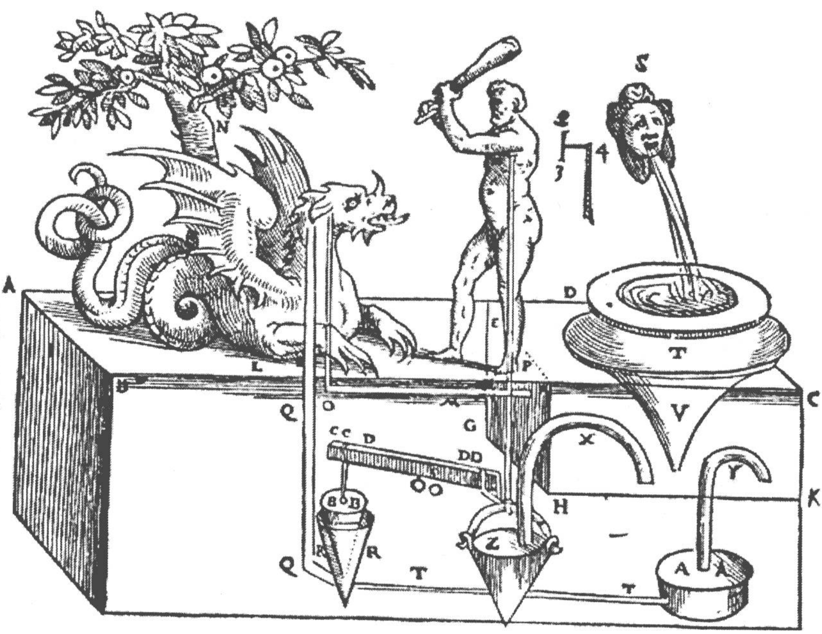

Figure 1.2 Water clocks designed by *Ctecibius* (270 B.C.)

Today's challenge is to consider robots as human coworkers and companions, extending human capabilities to achieve more efficient manufacturing and to increase the quality of our lives. This book focuses on industrial robotic coworkers. The fields of robotics that consider the companion aspects, namely service robotics and humanoid robotics, are not covered in this book. Nevertheless, the social perspective of using robots not only as coworkers, but also as personal assistants, is very promising. In fact, due to several social and economical factors, we are required to work until very late in life: It is common in Europe to only allow retirement when a person is near seventy years old. Since our physical and mental capabilities decrease with time, the possibility of having mechanical assistants that could help us in our normal routine has some valuable interest.

Robotics can be traced back to 350 B.C., in the ancient *Greece*, to the fabulous philosopher and mathematician *Archytas of Tarentum* (428-347 B.C.) and a demonstration he made in front of the *metropolis* senators. A strange machine that he called "*the pigeon*" was capable of flying more the 200m, using some type of jet propulsion based on steam and compressed air: a great achievement for the time (the invention of the screw and also the pulley are attributed to *Archytas*).

Figure 1.3 A Greek design adapted by *al-Jazari* for a garden hand-washer

In 270 B.C., also in ancient *Greece*, the civil engineer *Ctecibius* was capable of building water clocks with moving parts (Figure 1.2). His work had followers like *Phylo of Byzantium* author of the book "*Mechanical Collection*" (200 B.C.), and

Hero of Alexandria (85 B.C.), *and Marcus Vitruvius* (25 B.C.). In the twelfth century, the Arabian *Badías-zaman al-Jazari* (1150-1220) recollected some of the Greek developments in the book "*The Science of the Ingenious Devices*" [5] (Figure 1.3), and that is how they reached our time. In those early times the problem was about mechanics, about how to generate and transmit motion. So it was mainly about mechanisms, ingenious mechanical devices [5,6].

Then in the fifteenth century, *Leonardo da Vinci* showed indirectly that the problems were the lack of precision and the lack of a permanent power source. He designed mechanisms to generate and transmit motion, and even some ways to store small amounts of mechanical energy [7]. But he didn't have the means to build those mechanisms with enough precision and there was no permanent power source available (pneumatic, hydraulic, or electric). Maybe that was why he didn't finish his robot project [5,6], a fifteenth century knight robot (Figure 1.4) intended to be placed in the "*Salle delle Asse*" of the *Sforza* family castle in Milan, Italy. It wasn't good enough. Or it was so revolutionary an idea for the time that he thought that maybe it was better to make it disappear [5,6].

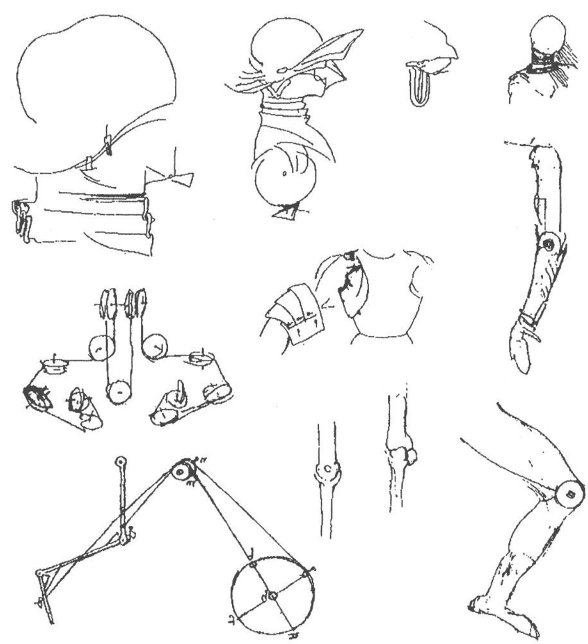

Figure 1.4 Leonardo's studies for a humanoid robot

And then there was the contribution of *Nicola Tesla* at the turn of the nineteenth century. He thought of using *Henrich Hertz's* discovery of radio waves (following the work of *James Clerk Maxwell* about electromagnetic phenomena) to command an automata. He built one (Figure 1.5) to demonstrate his ideas and presented it in New York's *Madison Square Garden* in 1898 [4,6]. The problem then was that machine intelligence was missing. Robots should be able to do pre-programmed operations, and show some degree of autonomy in order to perform the desired tasks. When that became available, robots developed rapidly, and the first industrial one appeared in the early 1970s and spawned a multi-million dollar business.

After that, robotic evolution was not as fantastic as it could have been, since there was a lot to do and the available machines were sufficiently powerful to handle the requested jobs. Manufacturers were more or less happy with their robots, and consequently industrial robots remained position-controlled, somehow difficult to program by regular operators, and really not especially exciting machines. Features currently common in research laboratories hadn't reached industry yet because of a lack of interest from robot manufacturers. Nevertheless, there was a considerable evolution that can be summarized as follows.

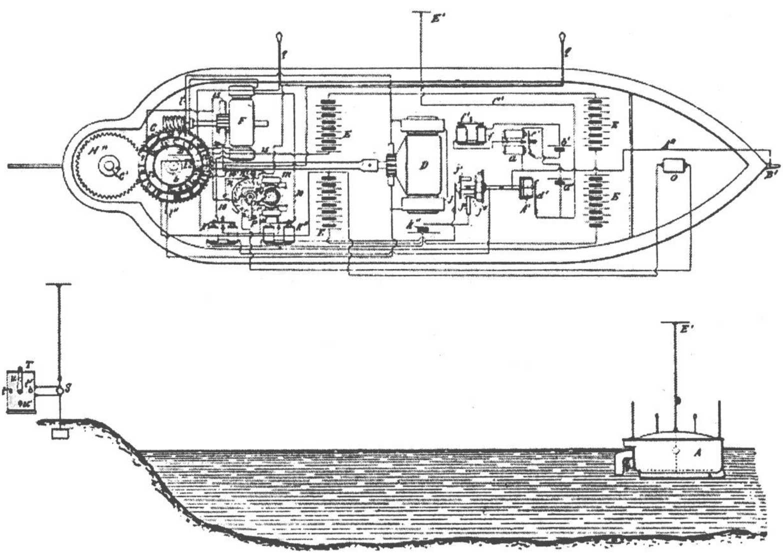

Figure 1.5 Nicola Tesla's remote-controlled miniature submarine

In 1974, the first electrical drive trains were available to use as actuators for robot joints. In the same year, the first microprocessor-controlled robots were also available commercially.

Around 1982, things like Cartesian interpolation for path planning were available in robot controllers, and many of them were also capable of communicating with other computer systems using serial and parallel interfaces. In the same year, some

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