Industrial Robot Handbook

Richard K. Miller, CMfgE

Industrial Robot Handbook

Richard K. Miller, CMfgE

Published by
THE FAIRMONT PRESS, INC.
700 Indian Trail
Lilburn, GA 30247

Library of Congress Data: LCC: 86-45550
Miller, R.K.
Industrial robot handbook.

ISBN: 0-88173-023-8

Industrial Robot Handbook

Published by The Fairmont Press, Inc.
700 Indian Trail, NW
Lilburn, GA 30247

ISBN 0-88173-023-8 FP
ISBN 0-13-463183-8 PH

Printed in the United States of America.

Distributed by Prentice-Hall, Inc.
A division of Simon & Schuster
Englewood Cliffs, NJ 07632

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall Hispanoamericana, S.A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Prentice-Hall of Southeast Asia Pte. Ltd., *Singapore*

INTRODUCTION

In 1981, Richard K. Miller authored a six-volume engineering report on industrial robot applications for metal fabrication, foundries, assembly, food processing, plastics manufacturing, and the electronics industry. The subsequent five-year period saw a boom in the U.S. robotics industry — with the robot population growing from approximately 4,000 to 20,000. During that time period, Mr. Miller's six reports were the leading publications on specific robot applications, guiding hundreds of manufacturing engineers in developing in-house programs. The six landmark reports have been expanded and completely updated by the original author, and combined into this handbook. It represents the most comprehensive compilation of industrial robot case studies ever published.

CONTENTS

Chapter 1

Robots in Industry

As of mid-1985, approximately 16,000 industrial robots were estimated to be in use in the United States. There are several reasons for their use and acceptance:

1. Reduced labor costs.
2. Increased output rate.
3. Elimination of dangerous or undesirable jobs.
4. Improved product quality.
5. Increased manufacturing flexibility.
6. Reduced material wates.
7. Easier compliance with OSHA regulations.
8. Reduced labor turnover.
9. Lower capital cost.
10. Controlled and faster inventory turnover.

The Robot Insitute of American defines an industrial robot as:

> A reportrammable multifunctional manipulator designed to move materials, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks.

The Japan Industrial Robot Industry Association uses a broader definition of an industrial robot:

> An all-purpose machine equipped with a memory device and a terminal, and capable of rotation and of replacing human labor by automatic performance of movements.

The Japan Industrial Robot Industry Association classifies robots by method of information input and "teaching" as follows:

1) manual manipulator--a manipulator that is worked by an operator.

2) fixed sequence robot--a manipulator which repetitively performs successive steps of a given operation according to a predetermined sequence, condition, and position, and whose set information cannot be easily changed.

3) variable sequence robot--a manipulator whic repetitively performs successive steps of a given operation according to a predetermined sequence, condition, and position, and whose set information can be easily changed.

4) playback robot--a manipulator which can produce, from memory, operations originally executed under human control. A human operator initially operates the robot in order to input instructions. All the information relevent to the operations (sequence, conditions, and positions) is put in memory. When needed, this information is recalled (or played back, hence, its name) and the operations are repetitively executed automatically from memory.

5) NC (numerical control) robot--a manipulator that can perform a given task according to the sequence, conditions, and position, as commanded via numerical data. The software used for these robots include punched tapes, cards, and digital switches. This robot has the same control mode as an NC machine.

6) Intelligent robot--this robot with sensory perception (visual and/or tactile) can detect changes by itself in the work environment or work condition and, by its own decision-making faculty, proceed with its operation accordingly.

These definitions can be used to distinguish between the U.S. and Japanese classifications of robots:

- "Robots by Japanese Definition" -- all 6 clases
- "Robots by U.S. Definition" -- classes 3,4,5,6.

"Robots"

The work "robot" was first used in 1923 in a play by Capek. The concept of robots was popularized by Isaac Asimov in the 1950 book, I, Robot. Asimov postulated Three Laws of Robotics:

1. A robot must not harm a human being, nor through inaction allow one to come to harm.

2. A robot must always obey human beings, unless that is in conflict with the first law.

3. A robot must protect itself from harm, unless that is in conflict with the first or second laws.

These laws still provide meaningful guidelines for robot researchers, manufacturers, and users.

Robotic Organizations

There are two robotic societies in the United States, both managed by the Society of Manufacturing Engineers.

Robotics International of SME is both applications and research oriented and covers all phases of robot research, design, installation, operation, human factors, and maintenance within the plant facility. It was founded in 1980 as an educational scientific association for robotics professional and is the worldwide organizational "home" for scientists, engineers, and managers concerned with robotics. Their address is"

Robotics International of SME (RI/SME)
One SME Drive
P. O. Box 930
Dearborn, MI 48128

The Robotic Industries Association (RIA) is the only trade association in the United States involved in the field of robotics. Founded in 1974, RIA supports the exchange of technical information between robot manufacturers, distributors, corporate users, accessory equipment suppliers, and those involved in robotics research. Their address is:

Robotic Industries Association
One SME Drive
P. O. Box 1366
Dearborn, MI 48121

Six robotic organizations outside the United States are listed in Table 1.

Robotic Manufacturers

There are currently over 100 manufacturers of industrial robots in the United States. Appendix A presents a list of these manufacturers classified by state. In addition, several manufacturers of robots in Japan, Sweden, Canada, England, and other countries import robots to the United States.

The Evolution of Intelligent Robots

The field of industrial robotics began in 1951 with a patent by George C. Devol for a "Programmable Article Transfer." The first industrial robot, a Unimate from Unimation, Inc., was installed in 1961 at a General Motors plant. The task was unloading a die casting machine (see Figure 1). All initial installations were fostered by Joseph Engelberger, founder of Unimation, Inc., who is considered the "Father of Industrial Robotics." Unimation's robots were based upon the concepts of George Devol, who is considered the "Inventor of the Industrial Robot." Both Mr. Devol and Mr. Engelberger remain active leaders in the robotic field. Unimation, Inc., was acquired by Westinghouse in 1982.

Two other firms which were pioneer manufactures of industrial robots were AMF Versatran (which later sold to Prab Conveyors) and Auto Place. In 1973, Cincinnati Milacron, led by Richard Hohn, developed the T^2 jointed-arm robot.

American robot technology was well received and enthusiastically installed in Japan. Most early installations in the U.S. and Japan were in the automotive industry. These trends continued until about 1980, when many American industries began to seriously investigate robot applications, and installations began to appear significantly outside of the automotive industry.

Early industrial robot installations were of three types:

- Machine loading and material handling
- Spot welding
- Spray painting

Applications involving greater precision, complex control and sensory capabilities began to be considered after the development of the PUMA (Programmable Universal Machine for Automation) by Unimation, Inc. The first PUMA robot was shipped to General Motors in 1978.

Since the initial installations, robotic engineers began to look ahead to future generation robots which would have vision and tactile sensing and intelligent control. These capabilities began to be developed in the mid-1970's with applied research projects at several major universities, such as:

- SRI International (Machine Intelligence Research Applied to Industrial Automation)
- Stanford University (Computer Integrated Assembly Systems)
- University of Rhode Island (General Methods to Enable Robots with Vision to Acquire, Orient and Transport Workpieces)
- MIT (Artificial Intelligence, Vision and Tactile Sensory Research)
- Charles Stark Draper Laboratory (Compliance for Assembly Robots)
- Purdue University (Advanced Robot Control Systems)

These projects were sponsored, in part, by the National Science Foundation. There were over 50 industrial co-sponsors, including both robot users and manufacturers.

Other major robotics programs at American universities and colleges include:

- Carnegie-Mellon University
  Robotics Institue
- University of Florida
  Center for Intelligent Machines and Robotics
- Purdue University
- Lehigh University
- Georgia Institute of Technology
  Material Handling Research Center
- Worchester Polytechnic Institute
  Manufacturing Engineering Applications Center

Advanced robotic investigations have also been on-going at the National Bureau of Standards and Jet Propulsion Laboratory. Several large U.S. industries have large robotics reseatch departments, including General Motors, Ford, and IBM.

Background on the U.S. Robotics Industry (Ref. 1)

In Mid-1985, the Robotic Industries Association (RIA) estimated that some 16,000 industrial robots were installed in the United States. About 35% of the installations are in the auto industry. Other major industries using robots include home appliances, aerospace, consumer goods, electronics, and off-road vehicles. Recent developments that give robots added intelligence such as machine vision, tactile sensing, and mobility make robots suitable for a wider range of industries. The near future will find robots used increasingly in industries such as testiles, food processing, pharmaceuticals, furniture, construction, and health care.

Robots offer substantial gains in manufacturing productivity, particularly when integrated into an automated system. The history of U.S. robot installations indicates that robots increase productivity by 20% to 30%. Since the majority of robots are applied to existing machinery, companies using robots can accelerate payback on current equipment while reducing the need for new capital investment. For example, it is far more cost-effective to buy robots to make existing stamping presses or machine tools 20% to 30% more productive than it is to buy one additional piece of machinery at a cost equal to or greater than the robots with less output.

The importance of improved productivity cannot be stressed enough. The future strength of our nation depends upon American companies becoming more productive and staying competitive in world markets. Other nations have recognized the need to automate and are moving ahead at full speed with government, industry and labor support. They have also recognized the importance of robot technology in achieving their goals. America will have to develop this same cooperative commitment to automation and robots will play a key role.

Despite the fact that the technology was invented in America, the Japanese have become the leaders at putting robots to use.

Estimates indicate that Japan has about 60,000 industrial robots installed as compared to America's 16,000. In the mid-60's, Japanese industries and government agencies recognized that the vast productivity potential of robots offered Japan a chance to become a far more powerful manufacturing nation. Nearly a decade ago (1975) Japan's Ministry of International Trade (MITI) targeted robotics as an industry to dominate. Incentive programs were created to aid their domestic robot suppliers and encourage the use of robots. These incentives included government sponsored research and development projects, tax benefits to manufacturers and users as well as depreciation allowances for robot users. National robot leasing programs, and more recently, direct funding or robotic sensor development reflect Japan's continuing commitment. These programs have been extremely helpful to the approximately 200 Japanese robot manufacturers and to the Japanese economy.

Robot use is likely to top the 90,000 level in America by 1990. It is important that the domestic suppliers retain a large share of the market so that jobs created in manufacturing robots are retained in the U.S. Also, for national defense reasons America should not be dependent on overseas suppliers for a tool as vital as the robot to our manufacturing strength.

Industry experts believe that many new job opportunities will be created by the robotics and automation industries, similar to the explosion of opportunities created by the widespread use of computers. Most experts agree that robots will not have a significant impact on employment levels in the near future. In the long-term, the accelerating use of robots may create temporary employment problems if our workforce is not prepared for the new job skills that will be required. America must plan for the future now by instituting job retraining programs, new courses of study, and by developing a positive attitude about the introduction of automation.

The fear of robots by American workers should be lessened by a greater awareness of the following facts: 1) most current robot installations involve the selection of robot over another form of equipment, not to replace a person; 2) robots in factories generally perform the hazardous, boring, demoralizing and repetitive tasks that allow workers to be removed from dangerous environments; 3) the increased productivity offered by robots can pave the way to a shorter work week, higher pay, and better working conditions; 4) higher productivity means fewer jobs lost to overseas manufacturers in competitive industries.

The real threat to the American worker is the failure of U.S. industry to make full use of robots and automation. In declining industries, the failure to automate can mean a massive loss of jobs when competitive pressures put companies out of business. In thriving industries, the failure to automate can lead to a major decline if overseas companies use automation to become more competitive. For example, the highly successful Japanese auto and electronics industries made extensive use of robots to become formidable competitors for their counterparts of America. These American industries have responded to the challenge, but not before suffering major losses.

As America heads toward the 21st Century, we need to recognize that robots are tools that can create a higher standard of living for all of us. While industrial robots boost our manufacturing output, the growing personal robot industry promises to make our homelife more enjoyable. It is only a matter of time before personal robot servants, guards, and companions are skilled enough and affordable enough to be in great demand. To help accelerate the growth of the personal robot industry, RIA recently formed the National Personal Robot Association.

SME/UM Delphi Study (Ref. 2)

In 1982, the Society of Manufacturing Angineers released the publication "Industrial Robot: A Delphi Forecast for Markets and Technology." The study, which because of its formalized time-related publications, is called a Delphi survey, is to be repeated at intervals to update its forecasts. The consensus views are the "best available opinion" at this time. The survey was conducted by Donald N. Smith, director of industrial development division, Univ. of Michigan, and Richard C. Wilson, professor of industrial engineering. The forecasts include:

- By 1990, robot sales will surpass the $2 billion mark.
- By 1995, 96% of the robots will be the "intelligent universal programmable types.
- By 1990, 25% of robots will have vision.
- By 1985, "scene analysis" capability for scrambled parts handling will account for 10% of U.S. industry purchases, 15% by 1990.
- By 1990, 20% of robots will have tactile/touch sensors.
- By 1985, 5% of robots will have adaptive control; by 1990, 20% in the aerospace and electronics industries will have it.
- By 1985, over one half or robots sold will be computer-equipped; by 1990, the figure will rise to 75%.
- By 1985, applications for self-propelled robots are expected in all industries; a steady growth is forecast through 1990.
- The vast majority of displaced workers will be employed in new positions, some as robot programmers and technicians. Only 6% will be terminated this decade, 2% in later decades.
- Workers safety will be a major gain. By 1995, worker injuries in factories will be reduced 40% as a result of robot

installations.

- Four-day work weeks will be common by the end of the 1980's, a direct result of productivity gains of 20-25% in the early 1980's and 30-40% by 1990.

- By 1985, average robot costs will be $35,000; $30,000 by 1990.

- The percentage of robots purchased in the U.S. from domestic manufacturers will not change between 1980 and 1990: 80% from U.S. manufacturers, 20% from foreign manufacturers.

- Stand-alone robots will account for 80% of robot sales in 1985 as compared to systems. In 1990, the rate of stand-alone robots will have dropped to 60%.

Future Directions In Robotics (Ref. 3)

Hasegawa makes the following forecast of unfolding robot technology:

- Materials: Lighter and stronger materials for robot structures will be developed. These will include both organic and non-organic substances. As a consequence, the size and weight of robots will decrease.

- Power Sources: Small, reliable, high-performance, low-cost artificial eyes, ears, and tacticle sensors will be developed and even low-cost robots will have recognition capability.

- Control Systems: Advances in microcomputer technology will dramatically improve robot control. Control system costs will also be greatly reduced.

- Communications Systems: Remote control of industrial robots will be enhanced through developments in fiber optics, wireless communications, etc.

- Processing Methods: New, non-mechanical processing methods such as laser beam cutting, welding and other high-energy processing methods will reduce the processing load on robots and make the design work for them simpler.

- Robot Body Structure: Utilization of biomechanical concepts will result in superior robot structures.

- Software: Robot use will become easier through the development of robot languages, self-diagnosing systesm and robot application technologies. Software will contribute to reducing the design work needed on robots.

- Integrated Systems: Techniques for integrating production systems of men, machines, and robots, as well as their peripheral devices, will be found. Further, their design processes will be computerized.

Based on these technological trends, Hasegawa states that "industrial robots will become smarter, smaller, quicker, lighter, stronger, more ingenious, easier to operate, more intelligent and less expensive than they are now."

Robotics: The Future (Ref. 3)

Robots with increasing intelligence, sensory capability, and dexterity are emerging. Initially, we see an increasing use of off-line programming of computer-controlled robots, using improved robot command languages. Provision will be made to include the role of sensors, such as vision and touch, in this programming. Later, self-planning will emerge as higher and more general commands are given to the robot. At this point, the marriage of robotics and artificial intelligence will be virtually complete. At the same time as all this is taking place, robotic hands will emerge. Also emerging will be robots with coordinated multiple arms and eventually even legs, supported by even more sophisticated control systems. As this evolution progresses, information and intelligence will become the dominant factor in robotics, with the manipulator devices and sensors shrinking in importance to the skeleton that undergirds this dominating "ghost in the machine."

References

1. Burnstein, Jeff, "Background on the U. S. Robotics Industry," Robotic Industries Association, June 1985.

2. Smith, Donald N. and Wilson, Richard C., "Industrial Robots: A Delphi Forecast of Markets and Technology," Society of Manufacturing Engineers and The University of Michigan, 1982.

3. Gevarter, William B., "An Overview of Artificial Intelligence and Robotics, Volume II - Robotics," National Bureau of Standards, NBSIR 82-2479, March 1982.

Chapter 2

How an Industrial Robot Works

Industrial robots are commonly used for a wide variety of basic industrial tasks: material handling, machine loading, welding, spray painting, and tool operation. A great range of capabilities are offered in commercially available robots: load carrying capacities up to 2000 pounds, speeds up to 50" per second and repeatabilities up to .0004". Mobility can be achieved with track mounted robots and computers can now provide any degree of desired control. None of these capabilities are available in any single robot system, and the applications engineer must have a good understanding of how a robot works in order to specify an appropriate robot system for a specific application. This chapter provides a description of robot functions and capabilities.

The limitations of robots must also be recognized: todays robots have limited vision and can not think. They offer limited flexibility in comparison with a human operator performing a variety of tasks. Robots find most suitable applications in performing repeatitive tasks, and even then, only after the design engineer modifies the industrial process or manufacturing operation to accommodate the robot. Figure 1 shows several industrial robots.

Robot Classification

Robots may be classified by six fundamental elements of operation:

- Coordinate systems
- Power supply
- Control
- Manipulative functions
- Programming method
- Memory

Table 1 outlines the basic robot types within this classification.

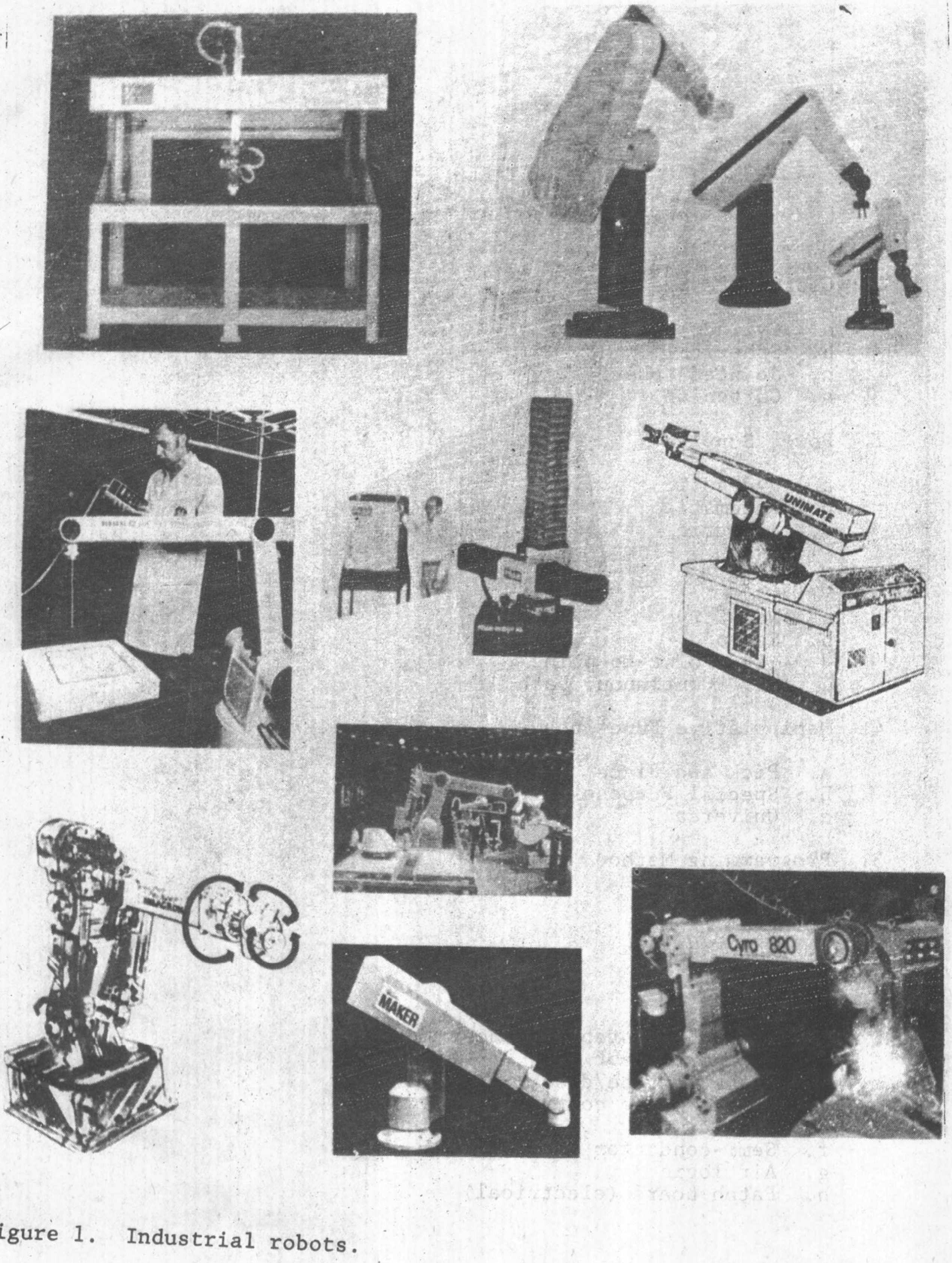

Figure 1. Industrial robots.