MANUFACTURING RESEARCH AND TECHNOLOGY 2

Computer-Aided Design, Selection and Evaluation of Robots

Nnaji, B. O.

MANUFACTURING RESEARCH AND TECHNOLOGY 2

Computer-Aided Design, Selection and Evaluation of Robots

by

Bartholomew O. Nnaji
Automation and Robotics Laboratory, Department of Industrial Engineering and Operations Research, University of Massachusetts, Amherst, MA 01003, U.S.A.

ELSEVIER
Amsterdam – Oxford – New York – Tokyo 1986

ELSEVIER SCIENCE PUBLISHERS B.V.
Sara Burgerhartstraat 25
P.O. Box 211, 1000 AE Amsterdam, The Netherlands

Distributors for the United States and Canada:

ELSEVIER SCIENCE PUBLISHING COMPANY INC.
52, Vanderbilt Avenue
New York, NY 10017, U.S.A.

Library of Congress Cataloging-in-Publication Data

Nnaji, Bartholomew O., 1956-
Computer-aided design, selection, and evaluation of robots.

(Manufacturing research and technology ; 2)
Thesis (Ph. D.)--Virginia Polytechnic Institute and State University.
Bibliography: p.
Includes index.
1. Robots, Industrial--Design and construction--Data processing. 2. Computer-aided design. I. Title. II. Series.
TS191.8.N58 1986 629.8'92 86-4513
ISBN 0-444-42614-0

ISBN 0-444-42614-0 (Vol. 2)
ISBN 0-444-42505-5 (Series)

Printed in The Netherlands

ACKNOWLEDGEMENTS

I wish to give special thanks to Professor Robert P. Davis of Clemson University, who was my advisor during the doctoral dissertation research, which paved the way for this book. I owe him deep gratitude for his advice and inspiration which have continued through the completion of this work. I would also like to thank Professors Marvin H. Agee and Charles E. Nunnally of Virginia Polytechnic Institute and State University, Jose M. A. Tanchoco of Purdue University and Richard A. Wysk of Pennsylvania State University for their suggestions during the research which culminated in this book.

I extend my appreciation and thanks to Professor Richard J. Giglio of the University of Massachusetts for his invaluable suggestions during this work.

Special thanks go to two students who through special projects helped in the completion of two of the chapters of this book. Reza Shafii helped develop the database management system which can be used to update the database of commercially available robots described in Chapter 9. Abbas Daryabeigi worked with me on a University of Massachusetts funded research project which resulted in the development of Chapter 10. Special thanks also go to Cameron Claussen of Smith College who through her summer internship research helped complete the material in the Appendix 2 of this book.

I wish to acknowledge Elizabeth Lambert, Stephen and Karen Strickland and the following students: Freya M. Toledo, Michael Duffey, Wu-Ji Li, Ashok Vishnu and Azam Zaidi who helped to proof-read and edit this book. I appreciate their help. I would also like to express my thanks to the students in the 1985 Industrial Robot Design, Selection and Implementation course who used various parts of this book and the associated software, CASOR and offered very useful criticisms for both the book and software.

My thanks to Phyllis Glazier, Terri Mushenski and Connie Chatterton for their secretarial assistance.

I take this opportunity to thank my wife, Patricia, for her assistance, advice and patience through the many years it took to make this book a reality. She helped type and edit this book. She shared with me the long hours necessary to produce a book, and I appreciate them.

PREFACE

This book is an adaptation of the author's Ph.D dissertation at Virginia Polytechnic Institute and State University. The dissertation, entitled "Computer Aided Design of Robots," provides a method of using information about a robot workplace and desired work tasks to "custom design" a robotic device for the given application environment. This design strategy assumes that a justification study for the implementation of robots has been done and that a robot is the desired automation for the workplace. The specifications obtained from this design are then used to shop in the real world for commercially available robots that can perform the desired tasks within the work place. To accomplish this objective, an expert system based FORTRAN software called CASOR, was developed which, through an interactive query and response, will produce prototype specifications for the application environment. With these specifications, it is now possible to shop for commercial robots.

Selection between even two robots can be very difficult, since many specifications are not simple quantitative measures of robot capabilities, but are rather complex issues which could require some expertise in the field of robotics. Shopping usually means perusing "tons" of pages in robot specification catalogs and comparing lists of specifications. CASOR is therefore provided with a database of commercially available robots which is equivalent to a computerized catalog of robot specifications, and which has built-in intelligence to check for feasibility and compatibility with the prototype.

Since the author became a member of the Engineering faculty at the University of Massachusetts, he has made some modifications and additions to both the original work and the software. With a technique called "Parametric Computer Aided Design of Robots" presented in this book, it is now possible to use the output of CASOR software, which includes the robot specifications, to provide a graphical (pictorial) display of the prototype robot on a Computer Aided Design (CAD) system. In order to pick the best robot from a set of alternative robotic devices, the author has developed a technique which evaluates the alternatives using both quantitative and subjective factors. This technique is a mathematical model which embeds such evaluative procedures as return on investment (payback) methods and captures hardware/software issues as well as vendo and internal adaptation issues. These techniques are also part of an update CASOR software. The subject of artificial intelligence is not treated in th book since artificial intelligence pertains more to the structuring and efficiency of the CASOR software than to the actual design and selection metho for robots. It will become quickly obvious by reading this book, however, tha some type of structured intelligent system is required to make the numerous dependent decisions which must be made in the process of designing and selectin robots. CASOR uses this structured intelligent system (artificial intelligence for its decision transactions.

The author believes that this book will be useful for design and system engineers in the field of robotics by providing design, selection and evaluatio guidance for them. Robot manufacturers and consultants and frequent users o robotic technology will also benefit from the book and its associated software CASOR.

Although not written as a textbook, this book could be used in a robotic course which emphasizes the robotic systems engineering as opposed to individua robotic subjects such as controls, dynamics or kinematics. These subjects ar presented in the book as tools in the systems engineering associated with th design, selection and evaluation of robots.

CONTENTS

FIGURES

TABLES

CHAPTER 1

ROBOTICS IN AUTOMATED MANUFACTURING

1.1 INTRODUCTION

Many industrialized nations have been experiencing a crisis in productivity as output per manhour continues to drop significantly. On the average, Japan's productivity shows the highest increase of all industrialized nations because Japan has managed to introduce modern technology into its production lines. Yet, despite Japan's success, other countries, including the United States, have resisted incorporating the most advanced technology into manufacturing processes.

The integration of robots into the production picture is one of the most promising ways of using technology to increase output per manhour and thereby improve productivity. For many industrial operations, robots, in fact, may be the cheapest, if not the only way to comply with safety regulations in both Europe and the U.S. Because the industrial robot is immune to many workplace hazards, it can present a cost-effective method of complying with regulations. Robots can replace humans in spray painting applications, for example, reducing the amount of ventilation equipment that must be installed. When robots load machine tools, many of the guards and interlocks required to protect human hands are no longer necessary. By using robots in welding processes, manufacturers can eliminate the costly safety clothes and ventilation equipment necessary to protect welders from the hazards of grinding, deburring, and other welding processes. Robots can also perform routines in many noisy industrial environments without the periodic breaks now needed to keep within Occupational Safety and Health Administration (OSHA) standards in the U.S. In some European countries, where health and safety standards are more strict than in the U.S., robots are already being incorporated into finishing operations.

A savings in safety equipment is only one contribution robots can make. A capital investment in robots is definitely justified by rising wages. Robert Greene of Prab Conveyors points out that in 1961, an industrial robot was priced at $25,000 and the labor rate was about $3.80 per hour in the U.S. Today, a better robot can be purchased for $50,000 but the labor rate has quadrupled. In the auto industry, the labor rate averages about $20 per hour. A quick glance at average annual increases in productivity for major developed countries betwe 1960 and 1977 tells an interesting story:

United States 2.8%
United Kingdom 3.0%
West Germany 5.7%
Japan 8.4%

Industrial production per manhour has been lagging especially in the Unite States, where economists consider low productivity a crisis. The government a well as industry wants to stop this trend since lower productivity contribute to inflation. Although the U.S. is used as an example here, many of the ailment characteristic of industry in the U.S. certainly exist in most other countri slow in realizing the benefits of modern technology, including robots. This boo describes a computerized method for designing and selecting robots, two task fundamental to their successful integration into industry.

Since automated production systems of the future will rely heavily o robots, design engineers will spend a significant amount of time searching fo the most appropriate robot for a given work environment or task. The enginee will need to know the various components of the robot as well as the dynamic and kinematics of the structural members of the robot. Today, most industria systems designers approach this problem by comparing robot specifications i manufacturers' catalogs. There is no doubt that this process is very cumbersom and will not always yield the most appropriate robot. Since the processes in volved in the design of an appropriate robot are not only associated with t geometric requirements but also include economic decisions and some subjectiv issues, the use of catalogs constitutes a very laborious exercise. This lev of combinatorial problem cannot be handled easily without the use of a computer

1.2 OBJECTIVE

The goal of this book is to provide a methodology for the design and selec tion of robots. This methodology will enable a designer to design a structura configuration to fit an applications environment and to use an intelligent sys tem to select robots' components through a database system. To achieve th end, the major components are established as structural data blocks. Each bloc is part of a hierarchical tree that goes from the major component to its variou types down to the primitives. Each level of the component structure has a se of quantitative, comparative qualitative and weighted qualitative decisions tha must be made to go from one level to the next. The primitive will constitute that level where the robot subcomponent has no further subclasses or where there is no valuable criterion to distinguish among types. Each block has characteristics associated with it which serve as a knowledge-base in the intelligent design/selection system.

1.3 APPROACH

This book and associated software, CASOR (Computer Aided Selection Of Robots), is designed to serve as a "consultant" to a robot buyer. For clarity, the robot buyer will be called the client and the robot consultant will simply be called the consultant. The client will supply the consultant with information about the workplace environment and the task(s) descriptions. The consultant will use the information to design and present the client with the most appropriate robot along with its components, and to provide an economic evaluation of the chosen robot(s). The procedure the consultant will use to recommend the most appropriate robot is described below.

The philosophy behind the approach proposed in this book is to provide the basic design for the best robot for any given workplace/worktask. The specifications for this prototype design can then be used to shop in the "real world" that consists of a database of coded descriptions of commercially available robots. Such "shopping" will yield a robot that matches or is better than the prototype.

1.4 MAJOR SECTIONS

The major segments of this technique are as follows:

1. **Component structure** (decision trees)

The selection of components for a robot is a difficult process, and even more difficult is the selection of subgroups of a given component. Choosing an electric motor, for example, requires a comparison of many motors across several criteria. In the component structure proposed here, the subdivisions will form a tree structure for the drive system. The same format is derived for the gripper, the sensory system, and the control system. This tree structure is called the blocks. Structuring the robot components in their appropriate blocks is then an important process in the component selection, and as such, a major contribution of this book.

2. **Codes**

The second major component is the coding system, which uses two classes of codes--monocodes and polycodes. Monocodes belong to the group in which each entry is predetermined from the outset of the coding process [109]. In the polycode, the meaning of an entry depends on the previous entries. This coding scheme is analogous to the COFORM scheme developed by Rose, et al. [109] at Purdue University. COFORM (Coding for Machine) acts as a medium through which data is passed to the Automated Process Planning and Selection Program (APPAS) [149]. COFORM takes on a combination of the monocode and polycode. In the same fashion, the coding system developed here takes on a hybrid scheme. After input data is divided into data blocks, a block is then analyzed in polycode format. But unlike the way COFORM operates, some of the codes here do not belong to major component blocks since some are merely design configurations such as degrees of freedom for a given robot. Choice of such codes is usually in monocode format. Just as COFORM is a medium for passing data to the APPAS, the coding scheme here is a medium for interfacing with the manufacturers' database. The coding scheme's other advantages will be enumerated later.

3. **Database**

The database structure provides the flexibility of representing the robot by codes as well as storing the manufacturers' published descriptions.

4. **Selection Algorithm**

This algorithm uses the third dimension of the coding structure, described in Chapter III, which contains the component characteristics as a knowledge base for selecting robot components such as gripper, drive system, sensory system and control system. This selection process is very important in component specification for robots.

5. **Design Specification Algorithm**

The design specification algorithm is the main body of this design approach and employs the use of the codes, the data structure (decision trees), the selection algorithm, and the database. This software provides specification for a robot including its dimensional properties and component characteristics. With this algorithm, a robot can then be defined in coded form and the code used to search the database for compatible robots.

6. **Mathematical Evaluation of Robot Components**

The objective of this section is to construct a mathematical model that captures:

(a) Critical issues such as minimum return on investment and budget ceiling.

(b) Objective issues such as investment and operating costs as well as savings. Depreciation of equipment is also incorporated.

(c) Subjective issues that sometime play a more important role in robot performance and user satisfaction; issues such as vendor performance and robot capabilities are captured in the mathematical model.

1.5 PROCEDURE FOR DESIGN OF ROBOTS

1. Use workplace/task information to determine the number of links and the degrees of freedom of each joint.
2. Use load and number of links to determine the physical properties of links (sizes in discrete form) and nature of the joints.
3. Using production (throughput) requirements, determine speed of the skeleton robotic setup.
4. With load and mass of the links, determine the torque, relative velocity and position using kinematic and/or dynamic equations for motion and position.
5. Choose the gripper mechanism based on load size and fragility.
6. Using the energy requirements, torque and velocity, go to the drive system data block and choose a motor setup.
7. Choose sensory system based on complexity of tasks.
8. Using the speed, motor type, workplace and complexity of tasks, choose control system.
9. Evaluate the feasible configurations (combinations) to determine an appropriate robot(s).
10. Using a mathematical evaluating system, determine the best robot.

1.6 SIGNIFICANCE OF THE APPROACH

The significance of this approach is far reaching in the systematic design of robots. An engineer who wants to design a robot for a given application will no longer have to persue large numbers of robotic catalogs: neither will the consultant. Any given robot can simply be described with a set of codes which will be denoted by a single dimensional array of numbers and letters. This code and its position in the array will uniquely describe a robot component along with its characteristics.

The use of this design strategy is not limited to the design of a robot. Robot manufacturers (buyers and consultants) can use the database and the design