THE WORLD YEARBOOK OF ROBOTICS RESEARCH AND DEVELOPMENT

FIRST EDITION

Consultant Editor:
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CONTENTS

THE WORLD YEARBOOK OF ROBOTICS RESEARCH AND DEVELOPMENT

FOREWORD

Most industrialized nations are entering an era where the rapid exploitation of advancing technology in manufacturing processes is becoming a crucial factor for their survival. Most governments are producing schemes for the special support of research and development, particularly in areas such as robotics. Such development is advancing at an unprecedented pace not only in university research laboratories but also in government and industrial environments.

In this era of turbulent change, it is essential for researchers, production managers and business managers to be aware of each other's work. It is therefore with great interest that one sees the appearance of this Yearbook. Produced using the latest techniques of office automation, it provides a desk-top data collection of unequalled value. Of particular interest are the articles that define up-to-date scenarios for research and development in robotics. These have been written to cover both the technicalities and the human implications of the advancing technology.

The international nature of PART 2: The World Directory of Robotics Research and Development Activities, is particularly welcome, as the only answer to future international competition is that it be an open one where work in different countries will proceed on a basis of collaboration and complementation.

The Yearbook is also intended for newcomers to the field who would rapidly establish the locations of those institutions with which they are most likely to collaborate. The listing of grant awarding bodies (see PART 3) may also help them in finding sources of support for their research. As far as the industrialist is concerned the Yearbook may be of direct relevance in finding advanced help from other sectors.

Finally, the browser might benefit as he will realize that robotics is advancing not only in a technological sense but also in its range of applications which spans from the heavy industrial assembly of machinery to delicate operations such as producing a wristwatch.

Igor Aleksander
Consultant Editor

INTRODUCTION

The World Yearbook of Robotics Research and Development is intended to be a comprehensive reference source encompassing the whole range of robotics and robotics related research in academic, industrial and governmental establishments worldwide. This book will be of use to researchers and students, to manufacturers and suppliers of robot systems, and to newcomers who might want to assess robotics in the context of their own needs. Indeed, it will appeal to anyone needing to know who is doing what and where in the field of robotics research.

While the concept of the book is based on a section of *The International Robotics Yearbook* (Kogan Page, London; Ballinger, Boston – 1983), all the information contained in PART 2: World Directory of Robotics Research and Development Activities has been obtained from detailed questionnaires. In order to identify, in the first instance, those individuals, companies and institutions undertaking robotics research, computer-assisted literature searches were made using databases in the UK and USA. Additional contacts were made through the cooperation of robot associations and other relevant trade organizations. The information contained in the returned questionnaires, plus any additional material such as previously unpublished internal reports, formed the basis for each of the entries listed in PART 2.

Robotics is a broad term embracing a wide range of disciplines and industries. We have tried to include details on all research that relates directly to robotics, eg vision systems, object recognition and manipulator control, but have omitted some research areas which are peripheral to robotics, eg computer languages or job design. Inevitably, judgements had to be made.

Details are given in PART 2 of 345 research groups working in 25 countries. Unfortunately, but perhaps inevitably, a number of institutions and companies have failed to return a questionnaire, despite repeated requests. It is hoped that these omissions will be rectified in future editions. Nevertheless, the relative number of entries in each section of PART 2 does correspond approximately to the level of activity in each country. The notable exceptions are the USSR, the Eastern bloc countries and China, where it has not been possible to obtain any detailed information. A number of institutions were mailed but, either through political or security considerations, failed to respond. Basic details of the research activities of many of the groups not replying to our requests for information have been taken from *The International Robotics Yearbook* (these entries are marked with an asterisk).

Several specially commissioned articles, written by experts and covering a range of topical subjects, provide an insight into the current state-of-the-art of robotics research; these make up PART 1: Robotics '85. In PART 3 information is given on the grants that are available for robotics research. Details of national coordinated research programmes and, where appropriate, contact addresses of the coordinating bodies are also given.

There are three ways of accessing the information contained in PART 2 – by the name of the organization conducting the research; by the name of a particular researcher; or by the areas of interest and/or field of study of a researcher or research group.

PART 4 comprises an alphabetical index to the organizations listed in PART 2; the full title of the organization is given, and a reference to the organization's entry.

PART 5 is an alphabetical index by surname of robotics researchers working at the organizations listed in PART 2; an abbreviated title of the researcher's place of work and the page number for reference to the directory entry are also given.

PART 6 comprises an alphabetical index of research activities; for each of about 230 keyword descriptors there is a list of the organizations involved in research in the subject field. The page number for reference to the directory entry is also given.

PART 1:
Robotics '85

DEVELOPMENT OF INTELLIGENT ROBOTS: ACHIEVEMENTS AND ISSUES

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INTRODUCTION

Robot characteristics

ROBOT CAPABILITY, COMPONENTS AND INTELLIGENCE

In the past there have been several definitions for the term 'robot', but none are adequate as they exclude robot intelligence of any kind. Therefore the following definition is proposed:

> A robot is a general purpose machine system that, like a human, can perform a variety of different tasks under conditions that may not be known *a priori* (Nitzan *et al.* 1983).

It is suggested that, being a general purpose machine system, the terms 'robot' and 'robot system' are synonymous. A robot system may include any of the following major functional components:

Effectors: arms, hands, legs, feet.
Sensors: contact, noncontact.
Computers: top controller, lower level controllers (including communication channels).
Auxiliary Equipment: tools, jigs, fixtures, tablets, pallets, conveyors, part feeders, etc.

A robot (or robot system) is controlled by a single top level computer (or controller). A group of such systems, which may or may not interact, are regarded as separate robots if they are not controlled by the same top level computer. However, by adding a single computer above them these systems will be merged into a single robot.

Although a robot performs some human tasks, and there is a similarity between the function components of a robot and those of a human (or a human team), a robot is not required to act or look like a human. It should, however, be able to perform tasks that require *flexibility*, which is the ability to perform a class of different tasks, and *artificial intelligence*, which is the ability of a machine system to perceive conditions that may not have been known *a priori*, decide what actions should be performed, and plan these actions accordingly. Some robot tasks can be performed by humans, others cannot (eg in a high-radiation environment).

ROBOT CLASSIFICATION

Like human intelligence, robot intelligence is variable. A Japanese classification of industrial robots (Sadamoto 1981) is categorized as follows:

(1) A slave manipulator tele-operated by a human master.
(2) A limited sequence manipulator (further classified into 'hard-to-adjust' and 'easy-to-adjust' categories).
(3) A teach-replay robot.
(4) A computer-controlled robot.
(5) An intelligent robot.

Incentives for intelligent robot development

SOCIAL INCENTIVES

The most important incentive for developing robots should be the use of machines instead of humans for undesirable tasks. For example, Japan is planning a large-scale programme for the development of robots operating in hazardous environments (Umetani & Yonemoto 1983). The ranking of robot development should thus be ordered according to job undesirability. For instance, tasks that are lethal (eg in high-radiation environments), harmful (eg paint spraying; handling toxic chemicals), hazardous (eg combat; fire fighting), strenuous (eg lifting heavy loads; visual inspection), noisy (eg forging; riveting), and dull (eg sorting; assembling).

TECHNOECONOMIC INCENTIVES

Another important incentive for robot development is the reduction of manufacturing cost of products, and the subsequent improvement of their quality.

Current Limitations Despite the above mentioned social and economic incentives, only a small fraction of the entire human work force has been replaced by industrial robots. Furthermore, Engelberger (1980) estimates that the growth rate of the total number of industrial robots (excluding tele-operators and limited-sequence manipulators) will rise from 2000 per year in 1980 to 40,000 per year in 1990; these figures correspond to a yearly replacement of about 0.003 to 0.06 percent of the total blue-collar work force in industrialized countries. It is suggested (Nitzan *et al.* 1983) that such a low rate of growth of robot population has resulted primarily from the following limitations on today's industrial robots:

(1) Insufficient material-handling flexibility. Workpieces and other objects can be handled only if they are indexed within tolerances that match the accuracy of the robot manipulator. Such restriction limits the flexibility of manufacturing, especially in batch production of a mix of products.
(2) Open-loop control. Tasks that require closed-loop feedback control to correct local errors cannot be performed. For example, today's arc-welding robots cannot track a joint of randomly variable shape and gap in one pass and adjust the torch movement

and welding parameters accordingly; this limitation excludes these robots from a huge market.

(3) Inability to detect and correct errors. Detection of unexpected errors and the recovery from them cannot be achieved; a robot system cannot verify that all the robot actions have been executed as planned. The resulting penalty may be costly. For example, if an error in a sub-assembly is not detected in-process, the cost of debugging and repairing the final assembly may be several orders of magnitude higher than the cost of correcting that error in-process.

(4) Restricted mobility. The locomotion of today's robotic carts is restricted to fixed guidance (eg by buried cables); these carts cannot navigate freely, avoid obstacles, or find their targets in an unstructured environment. Such a restriction limits the flexibility of material handling in batch production.

Future Capabilities The way to overcome the limitations of the 'muscle-only' robots is to provide them with intelligence, ie adaptive sensing and thinking capabilities. Such robots would then be able to compete more effectively with white- and blue-collar workers. Many industrial companies do not presently agree with this observation, but they will, though hopefully not too late, when the threat of worldwide market competition becomes unbearable.

SOCIOECONOMIC PROBLEMS

Development of intelligent robots may raise many problems, the major one being national unemployment. Obstruction by labour unions to the development of intelligent robots will only worsen the unemployment problem. In addition, many countries, especially Japan, will proceed with such development and, as a result, foreign competition will become stronger. This complex problem may be alleviated by the following three factors (Nitzan & Rosen 1976):

(1) New Related Jobs. An increased demand for skills related to intelligent robots directly (eg engineering, computer programming and manufacturing) and indirectly (eg professional training, marketing, shipping and servicing).

(2) New Unrelated Jobs. A shift to other jobs, especially in the service industry (thus raising the standard of living).

(3) Fewer Working Hours. Reducing the working hours per week with no reduction in standard of living.

Whether these factors will solve the unemployment problem remains to be seen, but in the meantime the current rate of intelligent robot development is low, amounting to robot evolution rather than robot revolution. Such evolution will enable society to adjust gradually, without adverse repercussions, to the advent of the intelligent robot.

Technical approach

The technical approach to intelligent robot development should be based on the application of artificial intelligence (AI) techniques to robotics under four engineering constraints:

(1) High Reliability. The robot must be robust; if it fails, it should be able to detect the error and recover from it, or call for help.
(2) High Speed. The robot should be able to perform its functions as fast as necessary.
(3) Programmability. The robot should be flexible (able to perform a class of different functions for a variety of tasks), easily trainable (for new tasks or modification of old ones), and intelligent (able to perceive problems and solve them).
(4) Low Cost. The cost of the robot should be low enough to justify its application.

Clearly, these constraints may conflict with each other. For example, increasing robot speed or lowering its cost may also lower its reliability. A trade-off, therefore, must be engineered for different applications according to the significance of each constraint.

Research and development topics

As discussed, a robot system may be divided into effectors, sensors, computers and auxiliary equipment. Robotics research and development topics associated with these major functional components include manipulation (of arms), end-effectors and mobility; sensing (in general), noncontact and contact sensing; adaptive control (which utilizes sensors to monitor and guide effector actions); robot programming languages and manufacturing process planning (which generate task-specific computer programs that are executed by the top level and lower level controllers). Past achievements and research issues related to each of these topics are briefly described in the following sections.

MANIPULATION

Robot manipulation involves the kinematics, motion trajectories, dynamics and control of a robot arm.

Kinematics

The location (position and orientation) of a robot wrist in a frame attached to the base of the robot arm is described as follows:

(1) Joint Coordinates. The angles of the rotary joints and the lengths of the sliding joints of the arm.
(2) World Coordinates. The Cartesian coordinates of the wrist position and the direction cosines defining the wrist orientation.

Joint coordinates must be used to command the robot arm to arrive at a given wrist location. On the other hand, humans prefer to describe the