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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

LEVEL II

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A102462
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Technical Note 102 - Robotics	5. TYPE OF REPORT & PERIOD COVERED Final
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Major Gary M. Gummersall	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Business Research Mgt Center Attn: AFBRMC/RDCB Wright-Patterson AFB, OH 45433	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Same as Block 9	12. REPORT DATE June 1981
	13. NUMBER OF PAGES 12
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Same as Block 9	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution Unlimited - Approved for Public Release

DTIC SELECTE AUG 0 5 1981 E

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Distribution Unlimited - Approved for Public Release

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Robotics
Industrial Robots
Robotics Application
Manufacturing
Robot Technology

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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ROBOTICS

TECHNICAL NOTE 102

1981

AIR FORCE BUSINESS RESEARCH MANAGEMENT CENTER
Wright-Patterson Air Force Base, Ohio 45433

INDUSTRIAL ROBOTS; THEIR APPLICATION AND IMPLEMENTATION: A SURVEY

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June 1981

INTRODUCTION

The purpose of this report is to act as an overview and primer for senior and middle managers, procurement contracting officers, and technical personnel interested in understanding or applying ROBOTICS as part of manufacturing technology both within the Air Force and within the Defense Aerospace Industry. The impetus behind this report is the rapidly declining productivity of the U.S. industrial base and our own DOD resources in terms of being able to provide reliable, quality products at minimum costs.

The report begins with a review of the prime motivations of civilian industry and DOD in making use of robotics technology. Next, Industrial Robots are defined and some key functional aspects are discussed. Potential applications and application limitations are reviewed. Finally, planning and implementation are discussed with an emphasis on hidden problems and costs and some suggestions from lessons learned by others.

WHY ROBOTS?

The prime motivations for the exploding market for robots in the United States are the continuous decline in productivity and highly inflationary wage rates in the U.S. over the last twenty years.

The U.S. is last in productivity growth among major industrialized countries with an average annual productivity growth rate of only 1.5 percent during the 1960-1979 time period. Comparatively over the same time period Japan's productivity grew at an average annual rate of 7.1 percent, Italy's grew at 4.4 percent, France's grew at 4.2 percent, Germany's grew at 4 percent, and the United Kingdom's grew at 2.3 percent. (1) Indeed, during the first two quarters of 1980 the U.S. had a negative one percent productivity growth.

Wages during this same time period have spiraled dramatically. In the early 1960's the average wage of the U.S. auto worker including fringes was $3.50 per hour. By the late 1970's the average wage of the U.S. auto worker including fringes was $17.50 per hour. (2)

Declining productivity makes the U.S. less competitive not only abroad, but at home. In 1960 the U.S. auto industry held 96 percent of the U.S. domestic automobile market. By 1979 this market share had dropped to 79 percent. (3) Drops of similar magnitude have been experienced in other major industries, i.e., electrical machine tools and calculating and adding machines which dropped from 95 percent of the market in the early 60's to 56 percent of the market by the late 70's time period.

Impact

The impact of the steadily declining productivity and continuously rising wage rates relative to other nations is clear. The U.S. will continue to lose market share both nationally and internationally. We and others will be forced to buy more and more goods from other sources and nations simply because we and outside customers of the U.S. can no longer afford our prices. Our ability to maintain an effective defense industrial base and an effective military will also become severely strained as we are forced to pay either our own high prices and/or buy more goods, potentially at higher prices, from external suppliers. All of these changes due to lower productivity will combine to reduce U.S. military and political influences around the world.

Although not all reasons for the declining productivity are clear, recent studies indicate capital investment and new technology have together accounted for 80 percent of all past productivity growth. (4) It appears from limited activity of a few companies in this country and overseas that investment in robot technology may be a very important key to improving industrial productivity in the United States both within the Defense Industry and within the Department of Defense establishment itself. Although estimates vary, approximately 3,000 industrial robots are in use in the U.S. today and between two and three times that number in Japan, with several thousand additional robots in other countries around the world. These robots are being used in automobile plants, aerospace plants, and all types of industrial and manufacturing technology for tasks ranging from packing materials and shipping boxes to handling foundry operations, machining operations, etc. Paybacks of one to two years on the $30,000 to $120,000 investments are being claimed for these robots. These claims are based on a robot's ability to work up to 24 hours per day without breaks, no overtime pay, ease of interchangeability between various types of jobs and high task reliability which reduces rejects and improves quality.

WHAT IS A ROBOT?

This section attempts to define an industrial robot and briefly discusses the key elements in a robotic work environment.

Robot Definitions

"An industrial robot is a programmable, multi-functional device designed to both manipulate and transport parts, tools, or specialized manufacturing implements through variable programmed paths for the performance of specific manufacturing tasks." (5)

"Industrial robots are devices that perform tasks too physically demanding, menial, or repetitive for a human to do efficiently. Industrial robots generally consist of an arm, to which an end effector (gripper, spot welder, drill, etc.) is affixed; a power source supplying electrical or hydraulic power; and a control unit providing logical direction for the unit." (6)

The key elements in these definitions are programmable and multi-functional. (7) Automatic and programmable machine tools have existed for many years in industry. The problem with both of these equipment categories is that they are very specialized to task type, the work pieces or output which they can handle and still generate a useable product. It frequently takes many weeks or months to adapt or retool a production line with these types of machinery for a new output. All of this is, of course, conducted at considerable cost. Further "at least 60% of U.S. manufacturing is done in batches too small for assembly lines." (7) A robot, depending upon the complexity of the task and sophistication of the system, can be reprogrammed in a matter of minutes.

Work Environment

The following are key elements/equipment that are required or must be considered in a robotic work environment in order to make a robot work. The level of sophistication and integration of the various elements will depend upon the task(s) to be performed.

The Robot

The electromechanical device and limited microprocessor capability that performs the task with greater or lesser assistance from the other elements below depending upon the manufacturer, user, and the sophistication of the task. Most of the robots currently in use in the world are hydraulically powered. The advantages of hydraulic power are that it is simple, i.e., there are few moving parts and hydraulic robots are physically very strong and fast. With a limited amount of microelectronics, they can also be made to perform as accurately as other types of robots. Hydraulically powered robots are highly reliable. Most manufacturers and many users claim in the range of 98% reliability on a 2 to 3 shift operation per 24 hour period. Most units come with some microprocessor controls. (See below) Electrically driven robots are becoming more common and although considered quite reliable some expert sources feel they haven't been on the market long enough to fairly evaluate them. (8) The advantages of electrical robots are that although they are not as strong, they are quite accurate and their power systems take less space. There are also a few pnuematically driven robots. Various performance characteristics of robots have been defined which deal with the dynamic accuracy, repeatability, stability, etc. (See the Robot Application Guide for a detailed discussion) (6)

Effectors/Tools

These are the devices that allow the robot to perform its tasks. They can be grippers, various welders and drills which the robot holds, etc. Because there are as yet no industrial standards for the exact form and specification of these tools, there is considerable variability among the manufacturers. Manufacturers generally offer a limited range of these type of tools. It is frequently the responsibility of the customer to design and build his own tools for his applications.

Tool Attachments

Depending on the task, the sophistication of the robot, and its mechanical accuracy and control systems, various jigs, specialized work benches, etc. may be required to hold or orient the work piece so that tasks can be performed. In some situations the robot itself may perform portions of these tasks. It is generally up to the customer to design and develop his own special tool attachments for his particular applications.

Feed Systems

Various feed systems may be required to supply the robot with the parts it will work on. These systems orient the part, provide certain feed rates, etc. Some robots perform some of these tasks themselves, but all robots must be fed work pieces in an efficient and timely manner and one which is safe for both the equipment and the human beings that work in the environment.

Distribution

These are the systems that take control of the work piece after the robot has completed its assigned tasks. The same general requirements and limitations exist with these systems as with the feed systems.

Robot Control Systems

"The sophistication required of a robot control system varies directly with the complexity of the task to be performed." (6)

(a) Open Loop Systems - Used in limited sequence robots, an open loop system controls robot motion by mechanical stops. No feedback is made to the controller. (6)

(b) Closed-Loop - In the more sophisticated robots, closed-loop systems are required for sophisticated tasks. Feedback is provided to the control system on a specific orientation of the robot effectors. This is compared to a set point or points and the controller directs adjustments or changes as appropriate. A sophisticated miniprocessor could provide this type of control. (6)

The most sophisticated and versatile type of robot controller is the minicomputer. (6) These systems could potentially store many different task functions and alternative sequences for many different robot systems, provide teach modes, sensor (tactile, vision) interaction, and sophisticated program flow modification capabilities. This survey revealed no such commercially available systems although several companies have various levels of such a system under development or in use for their own purposes. The Robot Application Guide (6) provides a detailed presentation on high level control systems.

Engineering

This involves all the planning, work environment studies, tool, and control system development and design, outlined above. Some manufacturers offer limited assistance in this area. There are some firms who specialize in providing this type of consulting service. (8) Generally the burden for all the engineering work has been assumed by the customer who frequently has no prior experience in this area.

ROBOTICS APPLICATIONS

Robot technology is currently being used in a wide range of industries and applications. The table below was extracted from the ROBOT APPLICATION GUIDE and gives a good overview of current applications technology:

CURRENT AREAS OF APPLICATION

Pick and Place - This is the utilization of the robot in moving objects from one place to the other in positioning materials in the manufacturing process. Tasks include material handling, grasping, transporting, and heavy duty handling.

Machine Loading - In this application, the robot is combined with another machine that accomplishes the material loading and tool changing. Examples of robot loading are numerically controlled milling machines, lathes, and automatic presses.

Continuous Path - This application involves a process in which a precise rate of motion may be required. Spray painting and welding are common examples. In both, the motion of the robot must be synchronized with rate of application or speed of the associated process. Some attempts have been made in using robots to apply epoxy resin for composite layout. In this example, the robots are used to spray the resin between the successive layers of graphite broadgoods.

Manufacturing Processes - A robot for this application is one which is dedicated to cutting, forming, finishing, or otherwise processing materials for manufacture. In the aerospace industry, robots are being used to drill and rout aluminum sheet metal and graphite composite panels. This application generally requires extensive tooling design work.

Assembly - This is largely still a research area and most of the current literature in this area is from research programs. A robot for assembly would be designed to mate or fasten parts together into an assembly. Assembly applications characteristically require a relatively more articulate robot with high level sensory feedback and control capability and complex tooling and parts feeders. Vision acquisition and force feedback systems that will provide better adaptability are areas receiving much attention in assembly applications.

Inspection - These systems appear very similar to assembly systems in that they may require precise control. A robot for this application will generally either position material, parts, or the precision measuring instrument itself for the purpose of checking some aspect of the parts or material. Examples of components used with robots for inspection are television cameras, linear diode rays, fiberoptics, lasers and photoelectric control modules. (6)

Aerospace Industry Applications - Although their numbers are not yet large, robots are being used for a wide range of applications by the aerospace industry. General Dynamics uses them to drill wing and body panels for the F-16 with high productivity. McDonnell-Douglas Aircraft, California is using robots to form composite materials for aircraft surfaces. McDonnell-Douglas Aircraft in St. Louis is using robots to position drilling tools for a windshield drilling on the F-15 production line. The robot handles several drilling operations at one time. Lockheed and Boeing are also using robots in various applications.

Generally, as the table above indicates, robots are good at and have been effectively applied to parts picking and placing, spraying, welding, deburring, routing, drilling, feeding riveters and other machines and some types of automatic inspections such as measuring windshield openings on body assembly lines.

Application Limitations

One of the major limiting factors in improving existing applications and implementing new ones is lack of standardization. Other key limitations involve high level software technology and sensor technology.

High Level Robot Software Control Systems

These are offline task programming systems which allow a task programmer to program robotic tasks at a macro level. The USAF has at least partially solved this problem with a special adaptation of the APT programming language. (9) However, this survey revealed no such systems commercially available.

Communications Input/Output for Task Control Languages, Systems and Robot Controllers

This is required so that the input/output signals between the task control languages/systems and the robot controllers are consistent and they can communicate effectively between each other. Currently no standards exist in this area.

Sensors

Sophisticated applications require control and feedback systems (software for the control, sensors for the feedback). Optical and tactile sensors are required for many of these more sophisticated applications. Some are working at this time, but there are still serious limitations in this area.

Sensor Interfaces

Standardization of input/outputs between sensors is necessary so that all types of sensors from different manufacturers have compatible input/output signals.

Effectors/Tools

Standardization is necessary here so that all manufacturer's grippers or effectors and robot tools have common coupling methods.

Improvements in all these are expected quite rapidly over the next several years and they will greatly increase the range and complexity of the tasks robots can perform.

PLANNING AND IMPLEMENTATION

A total systems approach must be taken; the total application and all its processes must be examined. (8)

Successful robotics applications depend upon careful planning and evaluation. Many factors must be considered. Review of considerable literature and interviews with several sources who have experience in engineering robot application suggests the following steps: (9)

(a) Have clear objectives in mind of what it is you want to achieve. Robots, with careful evaluation and planning, can significantly improve productivity. However, they are not necessarily the most effective and efficient solution to every problem.

(b) Look at the total application, not just the task a robot might perform. Look at all the processes and tasks involved in the application. What is the most efficient technology? It may or may not be robot technology. If new technology is implemented in one task or process, how would it impact the others up or downstream from this particular task or function. In one case a robot was inserted into a line on a task in which it was too efficient. The floor supervisor was continuously turning off the robot to allow the downstream stations to catch up. Much of the potential productivity gains were lost.

(c) Look at the end product (this doesn't necessarily have to be the final consumer product, but could be an input into another application). Look at the product function, design, and cost. Can the design be changed while not affecting function or quality and allow the use of a more cost effective technology such as robots. In one case a minor design change led to a robot welding application which provided much higher quality at much lower cost.

(d) Look at the types of tasks - can robots perform these types of tasks effectively. More important, is the volume large enough to justify the investment. One expert said that two to three years ago the minimum batch run was on the order of a 100,000 in order to make a robot application pay off. This is no longer true and will become less true as technology blooms and robots can perform a wider variety and much more complex tasks. However, each application requires a careful evaluation. It may be possible and cost effective, for example, to group tasks within a plant or between plants that were not previously grouped.

(e) Carefully examine the work environment relative to the task the robot is to perform - some things to consider in this area.

The physical workspace - How much space is needed within the radius of the robot arm, overhead, for the robot power supply, etc.

Software - Will the application require more sophisticated software than is commercially available and in use. If it's a very complex operation, you may have to develop your own. There is currently very little commercially available robot control software.

Computer Hardware - to support the above software. Generally it is not available from the robot vendor and must be purchased separately from another source.

Feed Systems - How does a robot get what it needs, i.e., the work pieces and tools. Depending upon the application you may have to develop your own. Currently robot manufacturers may offer some advice in this area, but they do not offer a broad range of feed systems.

Distribution Systems - same problems as with feed systems, i.e., what happens to the work piece, how is it handled once the robot finishes.

Tools & Attachments - not standardized. Except for very basic grippers etc., you will probably have to design and custom build your own tools and tools attachments.

Support Equipment - one expert estimates approximately $6,000 for the first robot and each additional six or seven robots after that. (8)

Maintenance Support - Can your personnel accomplish the necessary robot maintenance. Experts indicate good technical data is available for American made robots and that the necessary maintenance tasks are relatively simple for one with the skills of an aircraft mechanic.

Spares Support - When the robot breaks, and it will, can you obtain the necessary spares in a relevant amount of time? Experts indicate that U.S. manufacturers support in this area is generally good. Foreign spares support currently is questionable or not so good.

(f) Management and Labor Acceptance -

Management - Senior Management must be actively involved and actively support any robot applications project; this means more than just a sign off on the investment, this is an extremely high risk area and they should recognize all aspects of it and participate in the major decisions.

Middle Management - They must enthusiastically support robot applications projects; these are the people who have to make it work, if they don't enthusiastically support such projects - forget them. Present corporate experience indicates that the major resistance comes from management rather than labor, based upon a fear of the unknown and that they didn't know how to go about applying the technology. The middle managers were afraid of the penalties if their attempts at application of robot technology failed.

Labor - So far labor has accepted robotics applications reasonably well because they replaced humans on very dull, repetitive, or dangerous tasks. The labor unions are also beginning to recognize the need for productivity improvements in U.S. industry if the U.S. economy is to remain viable. Expect some resistance as robots take over more complex tasks, especially if the transition is rapid.

(g) Hidden Costs - It should be recognized that robot manufacturers market robots. None currently offer total or turnkey systems (some other nonmanufacturing firms are beginning to do this). The cost of software, computer hardware, engineering, feed systems, distributions systems, tools, etc. are all in addition to the basic price of the robot. How much of these you will need and the level of sophistication will depend upon your application. <u>Therefore, it is not clear that the paybacks claimed in the current literature are based upon the total cost of a robot system</u>.

(h) Conduct a very thorough rate of return/payback evaluation. (6) Examine all viable alternatives. Robot application should be considered as a system acquisition rather than as equipment acquisition.

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6. "ICAM, Robotics Application Guide," Technical Report AFWAL-TR-80-4042, Vol II. Materials Laboratory, AFSC, Wright-Patterson AFB, Ohio 45433. (April 1980).

   * This is an excellent overview of robotics. Much of the material summarized in this Technical Note came from this document. A must for anyone seriously interested in robotics applications. This publication is available to U.S. Government agencies through Defense Technical Information Center (AD B050811L). Requests from organizations outside the U.S. Government should be addressed to AFWAL/MLTC, Wright-Patterson AFB, Ohio 45433.

7. "The Robot Revolution"; Time (November 8, 1980).

8. Personal interview with Vern L. Mangold, VP, Kohol Corporation, Dayton, Ohio (May 16, 1981).

   * This firm is involved in robotics systems evaluations and applications design.

9. Personal interview with Lt Gordon Mayer, Air Force Materials Laboratory, Wright-Patterson AFB, Ohio (May 14, 1981).

   * Gordon Mayer's prior experience was with Unimation. Lt Mayer has done graduate research in robot engineering and worked with Unimation in engineering robots and robot applications.

Related References and Note

1. 1981 SME Publications Catalog published by Society of Manufacturing Engineers, One SME Drive, P.O. Box 930, Dearborn, Michigan 48128.
* This catalog provides a list and description of robotics publications and video tapes on robotics engineering and applications. Several sources indicated these publications are well written and very useful.

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