II.

Robot Technology

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Roots of Robotics Technology

The paper by Albus (see app. B, item 2) surveys the state of robotics technology. Robots have a dual technological ancestry that has an important effect on discussions about what they are, what they can do, and how they are likely to develop. The two ancestral lines are: 1) industrial engineering automation technology, a discipline that stretches historically over a century; and 2) computer science and artificial intelligence technology that is only a few decades old. Ideas about the nature of robots differ according to the importance given to these two technological roots.

Most modern industrial robots are extensions of automated assembly-line technology. This form of automation has not historically depended on computers, although microelectronics provides a powerful new tool for extending its capabilities. In this view modern industrial robots are closely related to numerically controlled machine tools.

From such a perspective, robotics is already approaching the state of a mature technology. Over the next decade, the most important impacts of robotics on the economy and work force cannot be considered separately from the impacts of industrial automation in general.

On the other hand, modern computer technology may provide future robots with new "intelligent" capabilities such as visual and tactile perception, mobility, or understanding instructions given in a high-level, natural language, such as "Assemble that pump!" The commercial availability of such capabilities may be one or two decades away.

In the view of some computer science researchers, robotics as a technology that will have significant social impact is still in its infancy. They estimate that, given sufficient research support, they could produce a flexible, intelligent robot for the market within this decade. A robot of this type will be able to move freely about an unstructured environment, and perform a wide variety of tasks on command with minimal reprogramming time.

This view stresses the need for continuing basic research in computer science related to robotics, particularly in "artificial intelligence. " Robots are seen as "stand-alone," reprogramable devices, capable of performing many tasks other than large-scale assembly line applications, for example, small-scale batch manufacturing, mining, or equipment repair.

Which of these views is most pertinent in terms of current policy issues will depend, in part, on whether such an "intelligent" robot would be economically feasible in the near future and whether it would meet a significant need in the industrial sector. It seems likely, in fact, that both types of robotics technology will eventually become important, but that their economic and social impacts will differ to the extent that they are used for different purposes in different environments. Furthermore, the time scale for widespread adoption will be significantly later for the "intelligent" machines.

Definition of Robots

It is difficult to establish a usable, generally agreed on definition of a robot. Experts use different approaches to defining the term. The problem of definition is further compounded for the public by images shaped by science fiction movies that bear no resemblance to robots currently on the market.

At the same time, it is important to have some common understanding of the term in order to define the state of the art, to project future capabilities, and to compare efforts between countries. Depending on the definition used, for example, estimates of the number of robots installed in Japan vary from 3,000 to over 47,000 (5). This variation stems in part from the difficulty of distinguishing simple robots from the closely related "hard automation"* technologies for transferring material.

The Robot Institute of America, a trade association of robot manufacturers and users, defines robots as follows:

> A robot is a reprogramable multifunctional manipulator designed to move material, parts, tools, or specialized devices, through variable programed motions for the performance of a variety of tasks.

This definition seems to describe the current state of the technology and is generally accepted by U.S. industry.

Industrial robots have three principal components:

1. one or more *arms,* usually situated on a fixed base, that can move in several directions;
2. a *manipulator,* the business end of the robot, is the "hand" that holds the tool or the part to be worked; and
3. a *controller* that gives detailed movement instructions.

Computer scientists add to this list a few capabilities that are not generally commercially available today, but that might be part of a general purpose robot of the future (6). They include the following:

4. *locomotion* some means of moving around in a specified environment;
5. *perception,* the ability to sense by sight, touch, or some other means, its environment, and to understand it in terms of a task—e.g., the ability to recognize an obstruction or find a designated object in an arbitrary location; and
6. *heuristic problem-solving,* the ability to plan and direct its actions to achieve higher order goals.

*The term "hard automation" refers to traditional custom engineered automated lines. Although they may contain some standard components, they are built to accomplish one specific set of tasks and often must be completely torn down and rebuilt when the manufacturing process or product design changes.

Technological Context of Robots

The principal technological context of robotics is the field of industrial automation. Most experts on industrial automation state that robots are only one component of a large collection of related devices and techniques that form the technological base of industrial automation (7). This view was expressed both at the workshop and in discussions of experts with OTA staff. Mechanical devices that performed tasks similar to those done by modern industrial robots have existed for centuries. The principal difference is that, whereas so-called "hard automation" is custom designed to a particular task, robots are standardized, but flexible and programmable units that can be installed in different environments with much less customization. (Some adaptation is still often required). Clearly, there is a tradeoff between the efficiency of hard automation and the flexibility of robots.

Since machinery will be integrated with the total design of a factory it may not be useful to distinguish robotics as an independent technology. A fully automated factory of the future might include the following components:

- a *computer-aided-design (CAD) system* that provides a tool for engineers to develop new products on a computer using an electronic display screen. The data base generated by the computer during the design phase is then used by other computerized parts of the factory;
- *numerically controlled machine tools* and other automated devices that fabricate components of the product, transport, and assemble them following instructions generated by the CAD system;
- *robots,* also operating under computer generated instructions, that transfer materials from station to station, operate tools such as welders and spray painters, and perform some assembly tasks; and
- *computerized information systems* that keep track of inventory, trace the flow of material through the plant, diagnose problems, and even correct them when possible.

All of the above technologies are currently under development and being used in some form. They will likely evolve into components of a fully automated flexible manufacturing facility.

Thus, there appear to be two parallel technological tracks along which industrial robots are likely to develop: 1) stand-alone standardized units that will have varying uses in many different environments; and 2) robotics technology that is integrated into complete factories that will, themselves, be flexible. Any assessment of the impacts of robotics would need to consider both types.

The Robot Market

The current structure of the industrial robot market—producers, users, and investors–is discussed in detail in the background paper by Lustgarten (app. B, item 4).

The principal uses of robots today are spot welding, spray painting, and a variety of so-called "pick and place" operations that involve simply picking up an object and putting it with a specific orientation in a predetermined spot.

The automobile industry is the largest user of industrial robots, in terms of the value of equipment installed, and probably will continue to be over the next decade. Other major current and potential future users are summarized in the Lustgarten paper. Once again, these estimates consider the industrial robot as an extension of manufacturing equipment. They do not consider possible new applications outside of manufacturing such as mining or equipment repair.

Domestic robot manufacturers appear to fall into four grous:

1. Traditional machine tool manufacturers such as Cincinnati-Milacron that have developed a robot product line.
2. Established firms such as Unimation that have specialized in industrial robots.
3. Large manufacturing firms, such as General Electric and, in particular, electronic computing equipment manufacturers such as Texas Instruments, that plan to be major users of robots and that have decided to build their own. These firms may choose either to retain the technology for their own use or to market their robots externally.

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4. Small entrepreneurial firms that develop new, innovative robots. This type of firm has been important in many sectors of the information industry, and could well play an important role in robotics.

The relative importance in the marketplace of these different types of firms will depend on and, in turn, influence the evolution of robotics technology. The history of the microelectronics market suggests that many innovative new types of robots will come from the entrepreneurs, while the large firms will have the capital and capacity to produce and market large quantities of heavy equipment. Also significant in this regard is the trend, common with most high technology firms, toward acquisition of small, innovative firms by larger industrial firms seeking either to diversify or to integrate their traditional product lines with new technologies.

Technology and Market Issues

A number of issues concerning the robot industry were identified in this project:

- *Industrial organization.—What* types of firms will play the most significant role in the production of robots and in innovation? Will robot use and production be concentrated in a few large companies? Will a variety of robotics products be available for many applications by diverse types and sizes of users? What will be the effects on the financial health of different types of potential producers and users?
- *Research and development (R&D).–* Should R&D stress applications or should it focus on fundamental work aiming at significant new breakthrough in the state of the art? What role should the Federal Government play in funding this research via agencies such as the National Science Foundation? What type of work should be pursued in Government research labs such as the National Bureau of Standards, and at what level should it be funded? What additional policies, if any, would be required to stimulate R&D in the private sector?
- *Government use.* —Are there particularly important applications of robots in the Federal Government that should be explored and developed? Experts at the workshop mentioned in particular defense applications and uses of robots for space exploration and oceanographic work.
- *Definition.* –The question of defining robotics and their context, while not a policy issue per se, is an important problem if any Federal action is contemplated to encourage their use or develop any R&D program. How the technology is defined may well determine the type of industry that will be helped by the programs, and influence the structure of the U.S. robotics industry.
- *Standards.* –Should the Government encourage the establishment of technical standards for robotics devices and components? Should standards be set for interfacing between robots and other automation and information technology? Would standards encourage the development of the robot industry and the diffusion of the technology, or would they prematurely freeze the state of the art?