STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

May 1972

# ROBOTS, PRODUCTIVITY, AND QUALITY

by

Charles A. Rosen

Paper to be presented at the 1972 ACM National Conference (ACM 72), Boston, Massachusetts, 14-16 August 1972.

Artificial Intelligence Center

Technical Note 66

# ROBOTS, PRODUCTIVITY, AND QUALITY

Charles A. Rosen
Staff Scientist
Stanford Research Institute
Menlo Park, California

## I INTRODUCTION

### A. Abstract

There is a growing national need to increase the real productivity of our society, wherein "productivity" is redefined to include such major factors as the quality of life of workers and the quality of products, consistent with the desires and expectations of the general public. This paper proposed the development of automation technology designed to increase quality, in all its aspects, at an acceptable cost to society.

The proposed program is divided into two phases. The first phase is designed to catalyze the potential resources of industrial concerns by developing two demonstrable systems that include general-purpose programmed manipulation and automated inspection. The second phase, witb longer term objectives, would aim at devising techniques to broaden the utilization of programmed manipulators and sensors, to provide supervisory control of these systems by human speech, and to develop a capability for automatic manipulation of two or more sensor-controlled "hands" working cooperatively.

### B. Background

Steam-driven machines, later supplanted by electrical motors and internal-combustion engines, provided the mechanical "muscle" to free man from onerous physical labor. Development and implementation of methods of control for processes and machines have led to automated fabrication of interchangeable parts. These basic changes in fabrication methods have culminated in the modern mass-production process, in which the complexity and intellectual requirements for each stage have been reduced so that primarily only manipulative skill, controlled by visual and tactile feedback, is needed to perform simple repetitive operations. Although the output of finished goods per worker has increased steadily and is a marvel of the Twentieth Century, there is mounting evidence of growing dissatisfaction among workers who no longer are trained, nor can function with pride as artisans.[1-3*] A New York Times editorial (March 1972) states it well:

> "The struck plant at Lordstown, Ohio, engineered to turn out 100 Vegas an hour, is a mainstay in G.M.'s hopes of stemming the inroads West German and Japanese small cars have been making in the American auto market. But its operations have been plagued by constant labor turmoil despite the supposed insulation of good wages, high general unemployment and a location in the conservative heartland of Middle America.
>
> "A kind of guerrilla warfare between workers and management has developed out of employee frustrations that differ only in intensity from those Charlie Chaplin immortalized in 'Modern Times' 35 years ago. The Lordstown workers, with an average age under 25, make no secret of their distaste for the empty, repetitive nature of their duties as nursemaids to a line on which a car goes by every 36 seconds and all the skilled operations are done by sophisticated machines."

Direct results of the above dissatisfaction are decreased output occasioned by work stoppages, slowdowns and absenteeism, and poor quality of product leading to increased repair costs incurred before and after leaving the factory.

It will be difficult if not impossible to turn the clock back. The present standard of living in industrialized nations cannot be jeopardized by reversion to Stone Age methods of providing for basic needs and satisfying expectations of coming generations of workers. An evolutionary step forward is required in automation technology to eliminate undesirable jobs and to augment man in new man-machine relationships that require more human skill and thought and lead to a restoration of his purpose and dignity.

*References are listed at the end of this paper.

The new automation will therefore have to take into account not only traditional economic justifications, but also the growing secondary costs incurred by poor quality, low yields, and worker dissatisfaction.

## II MAJOR GOALS AND GUIDES TO SOLUTIONS

There appears to be general agreement that an increase in so-called productivity is a highly desirable goal. The notion of "productivity" can no longer be expressed simplistically in terms of the output per worker per unit time with due regard to capital investment. Serious thought must be given to other important factors that may become dominant. In the following sections, consideration is given to some major factors that will directly affect the real productivity of the near and, increasingly, the far future. Therefore, these factors will serve as guides to necessary developments.

### A. Quality of Work and Product

There should be an upgrading of quality in the character of many jobs. The emerging blue-collar work force has, in general more education and higher expectations than the previous generation. It does not accept the prospect of being reduced to a group of unthinking "hand-eye" automatons. This attitude bears strongly on the quality of goods produced, the degree of absenteeism, and the acceptance of new methods that would increase efficiency. These factors directly affect the quality of acceptable products produced for given expenditures in labor, capital investment, and warranties. These improvements can be achieved by innovations in automation technology that result in assignment of dull repetitive operations to semiautonomous machines with trained, skilled workers responsible for one or more of such machines. Consequent improvements in quality (and quantity) will result from the upgrading of the average worker's job to that of skilled artisan and, more directly, from the performance of repetitive operations with controlled machine precision, no longer being dependent on mood or fatigue of dissatisfied workers.

### B. Consumer Expectations and Demands

The rising expectations and demands of consumers cannot be ignored. Major requirements are improved performance, safety, dependability, and reduced cost of repairs. These factors depend to a large degree on the high quality of product resulting from proper materials, workmanship, quality control, and inspection practices. Better workmanship can be attained by implementing the improvements suggested in paragraph A above. Greatly improved quality control and inspection appear possible through developing and using picture processing techniques applied throughout the fabrication process. Because of the availability of automated assembly and inspection techniques, there will be a strong impetus toward new designs, with an emphasis on quality.

### C. Response to the Market

A highly desirable development would be the capability of rapid response to the market, i.e., minimization of time and cost to effect changes in products. Such changes may be required to match competition, to capitalize rapidly on new techniques or new materials, and more importantly to meet increasing demand for customized products at mass production prices.

Considerable changes in production methods are needed to cope with this problem. Computer-assisted design techniques and numerically controlled machines are already well developed for effecting rapid modifications in parts fabrication. Assembly methods, however, have remained almost static for many years. Commercially available programmed manipulators ("industrial robots") represent the first relatively primitive attempt to provide assembly tools with the capability of rapid changeover. Major limitations are the absence of sensory coupling between tool and workpiece, poor manipulative capabilities, and lack of techniques for cooperation between two or more manipulators (no two-handedness). A new generation of programmable manipulative systems is required, integrated with visual and tactile sensors, all controlled by computers, assisted and supervised by trained humans. Such systems will provide means for rapid and economic "changeover" for new models or for customizing products.

### D. Conservation of Resources and Minimization of Pollution

Indirect but increasingly important factors affecting productivity are the growing need for more efficient use of resources such as minerals and water and the public demand for minimization of pollutant generation. There are at least three major ways in which advanced automation has an important bearing on these problems:

(1) With better inspection, quality control, and assembly methods, less scrap will be generated.

(2) In many instances, the recovery and recycling of valuable waste materials can be made economically feasible only by developing better sorting and materials-handling methods. Sensor-controlled manipulators, incorporating pattern-recognition techniques, can provide the means.

(3) Many large industries have old plants that are marginally profitable. Furthermore they may be producing pollutants to

an unacceptable degree. The modification or processes in these plants to meet present and future legal limits on pollutants may be prohibitively costly. A better case can be made to replace these plants entirely; the added costs of minimizing pollutants can be more than compensated for by increased efficiency of production made possible by new methods in automation.

The following excerpt from a statement by the Ford Motor Company, reported in the New York Times (January 7, 1972, page 34), is illustrative:

> "The executives spoke at a press showing of a new foundry here, 20 miles southwest of Detroit. The foundry makes engine blocks and other components and cost Ford more than $200-million.
>
> "It replaces a 50-year-old foundry in Dearborn, and has 15 to 20 percent more capacity yet will employ 500 fewer employees. Mr. Ford said that $24-million has been spent on pollution control for the plant 'to make it the cleanest and most efficient producer of castings that modern technology can offer.' Foundries are commonly among the leading air polluters."

Research in machine-intelligence techniques and current availability of inexpensive computer hardware, sophisticated picture-processing software, and programmed manipulators have set the stage for initiating developments leading to attainment of the above goals. In summary, it is proposed that new automation be aimed at achieving the following, at an acceptable overall cost to society:

(1) Upgrading the quality of jobs for workers.

(2) Upgrading the quality of products.

(3) Increasing the capabilities for providing customized products.

(4) Making more efficient use of resources and stimulating construction of new pollution-free manufacturing facilities.

## III PROPOSED RESEARCH PLAN

### A. Introduction and Background

The suggested research plan is designed to implement the major goals stated previously and would aim at the development of new devices, techniques, and integrated systems of hardware and software for advanced automation and quality control. The systems are intended to be as general as possible, yet to serve as prototypes for a variety of more specific applications in production, assembly, materials-handling, and inspection tasks in manufacturing operations. The aim will be to develop economically viable machine substitutes for several of the following highly developed human capabilities, which are now used extensively in relatively low-level jobs:

- Rapid and skillful manipulation, such as that required in picking, transporting, fastening, assembling, and tool handling.

- Sensing and interpretation. Although vision is probably the most important sense, other inputs--such as tactile, acoustic, olfactory, and temperature--must also be considered. The interpretation of sensory inputs (a process that has often been called pattern recognition) is a high-level function of human intelligence and often demands extensive logical, problem-solving, and "educated guess" capabilities, together with a large store of accessible "facts" about the world.

- Rapid "learning" and retraining. A relatively unskilled worker can be taught a new routine by means of human speech, written instructions, or demonstrations of operations. From this basis, with some practice, he becomes sufficiently adept in the performance of these repetitive operations, and can also be retrained to do similar but new operations effectively.

The versatility of man in exercising all these capabilities is not exhibited by any existing machine nor is it likely to be in the near future. Nevertheless, this versatility represents an "ideal" that defines the goal of current work in automation. It is believed that significantly useful portions of such capabilities can be developed in the next few years, leading to economically advantageous industrial systems. Existing systems, available knowledge, and requirements are briefly reviewed below. Later sections propose specific research tasks.

#### 1. Industrial Manipulators

The present generation of commercially available industrial manipulators barely begins to approach the capabilities described above. Industrial "robots" such as the Unimate,* Versatran,† IBM 1972 Production Terminal,‡ and a number of others,§ are multiple-degree-of-freedom manipulators, which can perform simple material-handling and tool-using tasks repetitively once they have been programmed by a human for a sequence of operations. Programming of the machine for a single specialized

* Unimation Inc., Danbury, Connecticut

† Versatran-Thermatool, New Rochelle, New York

‡ International Business Machine Corp., Oswego, New York

§ More than 50 Japanese and several British companies are manufacturing or intend to manufacture industrial robots similar to the U.S. machines.

job is now simple, and a trained, but not necessarily highly skilled operator can manually guide the machine through a sequence of desired positions, altering and refining each step until a satisfactory sequence is obtained. In this programming mode, accurate spatial data for each degree of freedom for each position are derived from internal feedback sensors and are recorded on drums or tape. In the playback mode, the manipulator retraces the steps that have been recorded for each sequence and repeats such sequences thereafter with a high degree of accuracy. Evaluating the performance of existing industrial robots in terms of the ideal characteristics noted above, it is evident that rapid learning and retrainability features have been incorporated to a useful degree, but manipulative skill is rudimentary. Also, there is no provision to integrate important sensory information to guide and control manipulative operations. Thus, moving objects (or objects not precisely prepositioned for subsequent manipulation) cannot be handled. Furthermore, because of the lack of available visual and tactile sensory feedback and machine intelligence techniques, operations requiring the cooperation of several fingers or hands for manipulation of tools or objects cannot be performed.

2. Sensors

At present, the most widely used "visual" sensor applicable to industrial automation is the "on/off" light-sensitive electronic switch (photocell plus amplifier). Usually this device provides an inexpensive means for determining the presence or absence of a moving object or part of an object at a specific location and thus for electrically controlling some other associated process. Arrays of such photodetectors based on modern semiconductor technology have also been developed. Together with suitable logic circuitry, these arrays can usefully recognize two-dimensional figures, such as printed characters on a document or coded marks on a card or package. These optical readers usually require close and constrained physical coupling between sensor and sensed graphical data. More recently, optical scanning systems have become available for remote sensing.* In these, a collimated optical beam scans labels or marks affixed to packages, and the printed coded marks are read and decoded, providing important information useful for such functions as costing, inventory, or routing. These new scanners (see Figures 1 and 2) thus are beginning to provide, under constrained conditions, a simple and useful version of the wide range of information obtainable by humans using their eyes and interpretive faculties. As yet no commercial system is available that is capable of identifying an object or package in random position (or in motion) without the use of auxiliary coded marks. New techniques are now being developed in the

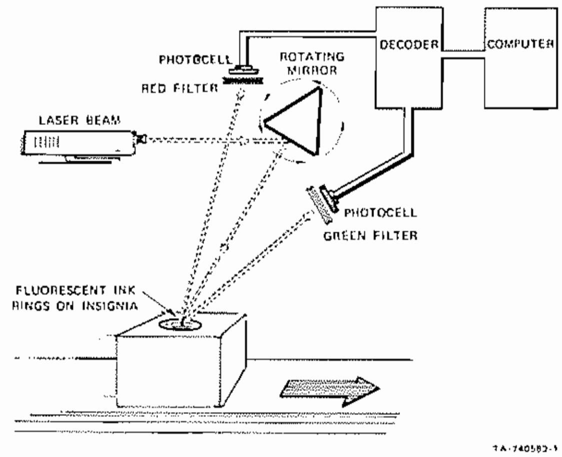



FIGURE 1 REMOTE LABEL READER. A set of circular concentric encoded marks printed on a label in two fluorescent colors are scanned in one plane using a 1-millimeter-diameter laser beam. Photocells with red and green filters sense the returned scattered light signals, which are then decoded for identification of the package to which the label is attached. Labels can be read at distances of from several inches to feet, in any orientation, (under development at SRI).

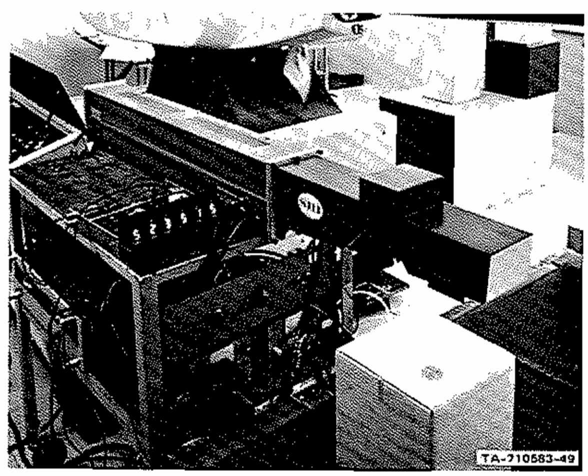



FIGURE 2 REMOTE OPTICAL SCANNER. A laser beam is swept across a specially coded label affixed to a moving carton. Sensing and decoding can be accomplished regardless of position and orientation of the affixed label.

laboratory to bridge this gap. One approach is based on the development of several forms of optical range finders (see Figure 3) that will yield three-dimensional data, which can be interpreted to describe the physical outlines of the object (or a convenient part of the object). Such data would be useful for recognition of the object, as well as determination of its position, its attitude in space, or its relative motion. Range data of this kind, incidentally, are believed to provide the bat and seal with sufficient information for them to cope with the environment. Another approach makes

*A commercially available remote label reader has been developed by Bendix Corporation

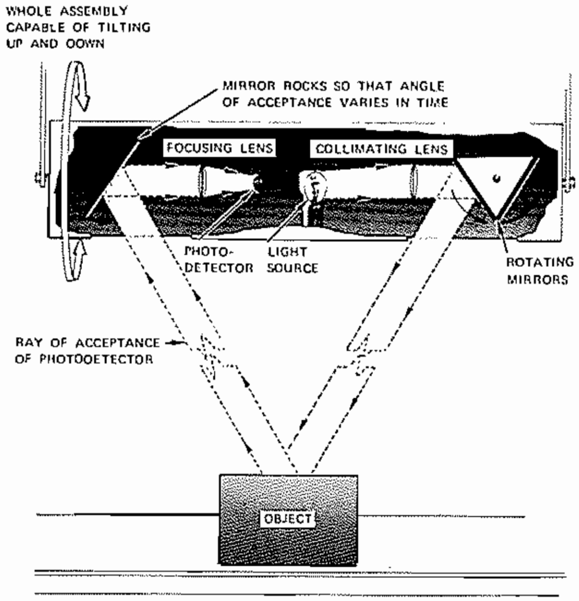



FIGURE 3 TRIANGULATION OPTICAL RANGE FINDER. A collimated light beam is caused to scan mechanically a field of view. Scattered returned light is received by a mirror-sensor system displaced a known distance from the light-transmitting mirror. Relative angles of transmission and reception are measured and distances to the points in the field are computed by trigonometric relations. A raster of range (or depth) points is thus obtained. (Under development at SRI.)

use of a television camera, which takes pictures of the object. When processed by a digital computer, the resulting data can yield descriptive information useful for the similar purposes as noted above. Considerable software to implement such "picture-processing" techniques has been developed over the past ten years,[4-21] but no general application to useful industrial tasks has yet been made.

The systems that use the two types of optical scanners noted above, i.e., label (or printed mark) readers and range finders, appear to be simpler and much less expensive than TV systems for integration with programmable manipulator systems and for other material-handling applications.

In many instances, manipulation control can be facilitated by using tactile sensors appropriately mounted on the industrial hand. In such operations as grasping or lifting delicate irregular-shaped objects, it may be necessary to control the forces exerted on the workpiece. In other applications, visual sensing can be dispensed with entirely through using multiple tactile sensors that, with the aid of a computer, can "discern" shape and orientation of workpieces for subsequent manipulation. Multiple-pressure (and force feedback) sensors are now under development[22-24] that, when integrated with manipulator and computer, can provide the digital dexterity required to manipulate tools or delicate parts in assembly and disassembly operations* (see Figures 4 and 5). An

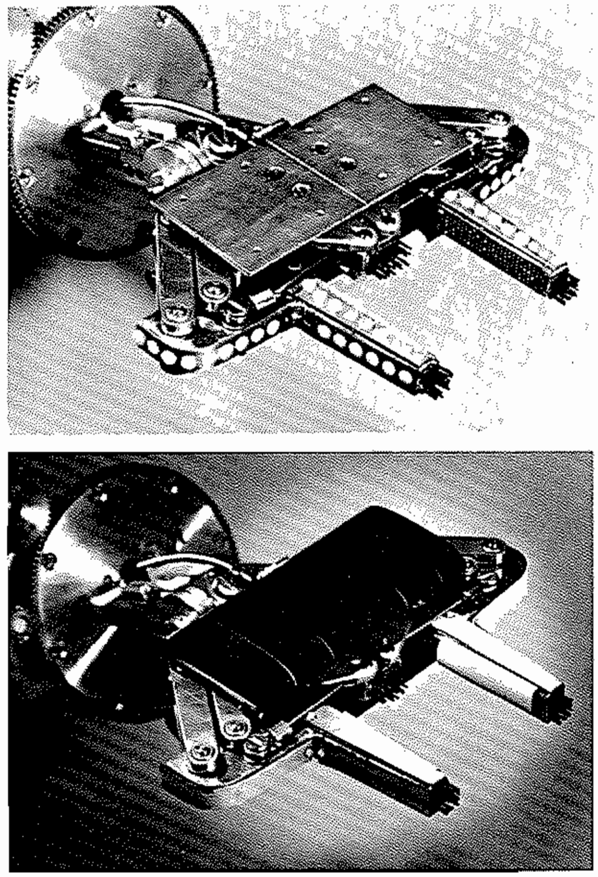


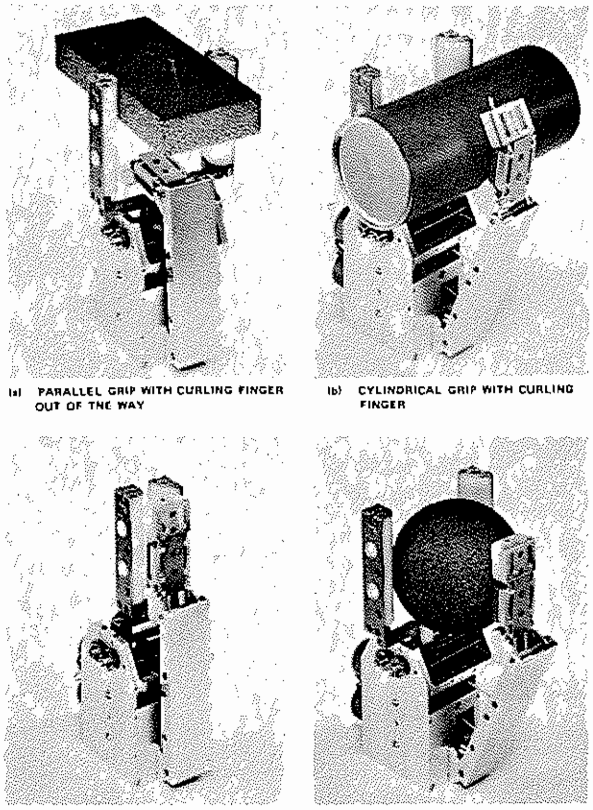
FIGURE 4 TOUCH SENSORS ON RANCHO HAND. Upper photo shows contact sensors bonded to tongue and wrist. Both whisker and planar sensors use flexible conducting rubber membranes. Lower photo shows finished assembly with conducting rubber covers in position.

important goal will be to devise software capable of coordinating mechanical actions of controlled fingers and ultimately the actions of two hands working cooperatively.

### 3. Visual Inspection and Quality Control

Visual inspection or quality control is a ubiquitous and often a necessary operation in all stages of the production process. It is often an implicit function; i.e., staged assembly of a product cannot proceed unless the right parts are at the right place at the right time and each of the parts or subassemblies has been properly fabricated in prior stages. Thus the main job of an assembler may be to fasten parts together or add to a subassembly. He must, however, ensure--through visual

*Hitachi, Japan has several tactile sensory systems under active development.



(a) PARALLEL GRIP WITH CURLING FINGER OUT OF THE WAY

(b) CYLINDRICAL GRIP WITH CURLING FINGER

(c) PARALLEL ALIGNMENT OF ALL FINGERS

(d) THREE-POINT PARALLEL GRIP

TA-760583-1

FIGURE 5 GRIPPING POSTURES OF THE SRI-SU HAND

inspection--that he is able to proceed. In many other instances, explicit inspection is necessary to avoid the generation of scrap, such as in the output of a high-speed stamping operation or to assure the quality of a finished package or product. In these cases, the main job of the worker is to inspect. The majority of both implicit and explicit visual-inspection functions are qualitative or semiquantitative in nature, answering questions such as:

(1) Are any parts missing from the subassembly?

(2) Is the part malformed or deformed?

(3) Is the package or part soiled, cracked, or otherwise blemished?

(4) Is it the right part for a given model?

(5) Are parts in the right relative positions?

(6) Is there evidence of excessive die-wear?

At present, there are no general-purpose machine substitutes for these forms of human qualitative and semiquantitative inspection capabilities. In some applications, such as in the fabrication of microelectronic integrated circuits, inspection is so tedious that automatic inspection is likely to be more reliable than human inspection. However, techniques of processing images derived from television pictures, using available principles, can be applied to a broad class of visual-inspection and quality-control problems (see Figure 6). There is a need

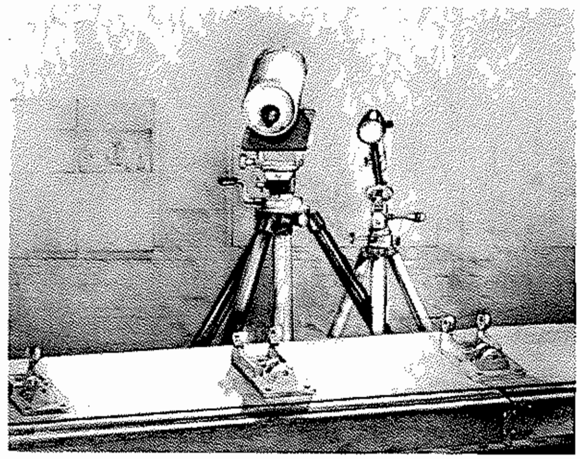


FIGURE 6 TELEVISION-COMPUTER PICTURE-PROCESSING SYSTEM. An object in motion is illuminated by a triggered flash lamp(s). A single frame TV image is stored, to be subsequently read off by the internal electron-beam scan. After analog-to-digital conversion, a raster of intensity points is stored in computer core, serving as the data base for subsequent processing. In this illustration the damaged part is detected by comparison of selected features with those of a stored "picture" of an acceptable part. (Under development at SRI.)

to assemble complete integrated systems composed of TV camera, optics, and electronics all interfaced with a digital computer to demonstrate solutions of typical problems, to permit economic assessment, and to provide the basis of design for specific applications.

4. Cooperation of Multiple Manipulators

There are no instances today of two manipulators operating cooperatively in a completely autonomous mode. The development of general-purpose, integrated sensor-manipulator-computer systems can lead directly to the cooperative coupling of two or more manipulators through the common computer. Software techniques suitable for such control have not as yet been devised and will be difficult to develop. However, it is hoped that when initial techniques for control of two manipulators are available, extension of control to three or more may be facilitated. In that event, completely new methods of assembly will be possible, since all present assembly is based on the use of fixed jigs and two-handed workers. Similarly, the impact on product design may be large, since this important part of the mass-production manufacturing process depends to a large degree on methods of fabrication and assembly.

This problem area is in many ways highly challenging, but progress will be slow. Advanced techniques in modeling, problem solving, and system integration now under active development by large artificial intelligence groups will provide some guidance but no immediate solutions. Initial studies will have to be made to specify precise needs, preferably in well-defined practical situations, with contributions from product designers, tool designers, production and manufacturing managers, and the marketplace.

5. Supervisory Control Implementation

We have assumed that semiautonomous machines must be able to be supervised in an overriding control mode. This of course can be effected by using switchboards, joy-sticks, teletypes, or variations of these. A more general means of such control would be based on the recognition of human speech. Several large "speech understanding" programs have been initiated in the past six months* in which it is hoped to develop the capability of understanding flowing human speech utterances, limited to a vocabulary of 1000 words in a specified domain of discourse. Other programs exist[26-28] in which a small number of key words and phrases can be recognized when spoken one at a time, such as the digits. A useful intermediate result of the more complex programs above could well be the capability of recognizing phrases spoken in English, with a system sufficiently powerful to permit a rich choice of selected adjectives and adverbs with verbs and nouns, all within a prescribed vocabulary, such as:

"a little higher"

"to the right"

"stop at once"

"six inches, forward"

"cancel last command"

"repeat last step."

If such a capability existed, one can envision a supervisor being able to use eyes and voice to assume control of the operation of a machine in a natural and unimpeded manner. His control would be timely and rapid, and it would require minimal training. Certainly, methods entailing manipulation of switches or keyboards or both could augment his control capabilities, where required.

*These speech understanding programs are under way at Bolt, Beranek and Newman Inc., Cambridge, Massachusetts; Carnegie-Mellon University, Pittsburgh, Pennsylvania; System Development Corporation, Santa Monica, California; Lincoln Laboratory, MIT, Cambridge, Massachusetts; and Stanford Research Institute, Menlo Park, California.

B. Proposed Research Tasks

1. Rationale

Present R&D expenditures in this field by U.S. industrial concerns are small because of a lack of knowledge of what can be done and a lack of confidence that cost-effective systems can be devised in the near future. Most U.S. companies are definitely interested in increased productivity and are disturbed about the rapid increase of foreign competition and the rising disaffection of workers. However, as yet they are unprepared to make the substantial commitments required in trained people, hardware, and software to mount adequate programs.

In the aggregate, the R&D establishments of these companies have resources dwarfing those available to universities, government, and nonprofit research establishments. It is therefore proposed to include a component designed to catalyze these potential resources by having high promise of useful results attainable at an early date. It is thus recommended that the research be divided into two phases: an initial short term program, in which available technology would be exploited to demonstrate and evaluate several systems with general applicability and a longer term program in which new techniques, sensors, and systems would be developed and expeditiously introduced into industry. Continual guidance for directions and the main thrust of the long-term program would come from industrial experience and acceptance of these new systems. Several components of both short- and long-term programs are described in the following sections. They are designed to be suggestive, rather than complete; a detailed treatment is yet to be made. However, the components are general enough in scope that, if successfully implemented, the results could be widely introduced into practice and generate the confidence required for expansion on a large scale.

2. Phase 1: Short Term Program

The objective of Phase 1 would be to develop several programmable laboratory systems incorporating software and hardware packages, which could convincingly demonstrate advanced techniques. Candidate systems include sensor-controlled manipulation and visual quality control.

a. Sensor-Controlled Manipulation

The needs are to:

(1) Develop appropriate visual and tactile sensors and incorporate these sensory subsystems with the manipulator into computer-driven integrated systems.

(2) Develop software "training" methods that retain all or most of the advantages of present "training-hy-doing" methods of programming machines.

Advanced manipulative systems, such as proposed above, would find their greatest use in mass production and customized assembly, in tool-feeding and in materials-handling operations. Figure 7 shows an artist's conception of a representative system, together with a laboratory test-bed for development.

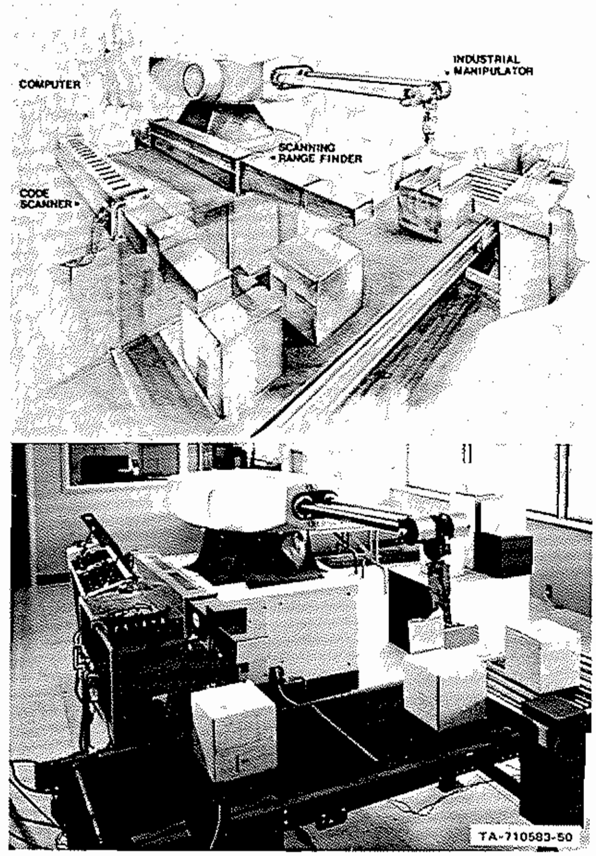



FIGURE 7 MATERIAL-HANDLING SYSTEM. The upper illustration is an artist's conception of a laboratory test bed for an automated material-handling system. A label scanner can be used to identify the package. A scanning range finder interfaced with the computer can sense contours of the package to determine the package's angular and translational position, such that the manipulator can adjust its programmed actions to pick it up in general position. The lower illustration shows an SRI laboratory set-up with a UNIMATE manipulator and label reader operating on a package transported by a conveyor.

b. Visual Inspection and Quality Control

The needs are to:

(1) Assemble an integrated system of TV camera, optics, light sourees, interfaeing electronies, and digital computer together with basic software controlling all functions.

(2) Initiate development of a library of computer programs that will be able to extract essential features from the stored image of a viewed object, such as line or edge detection, hole detection, hole size measurements, scratch and crack deteetion, recognition of simple shapes, counting operations (such as for holes or pins), and detection of specified color of specified regions. There also should be included a facility for matching partial regions or zones with appropriate templates stored in computer core.

(3) Initiate development of simple user programming techniques, such that jobs can be set up rapidly and inexpensively. In general, it will be necessary either to store multiple images representing different orientations of the suhject to be viewed, or to provide software for computing the rotated views, with reference to a standard position. A desirable mode of operation might consist of televising a standard object in several prescribed positions, and storing essential features for each position to serve as templates for comparison with production objects to be inspected.

3. Phase 11: Long Term Program

In our opinion, it will be highly impracticable to develop a completely automated factory, distribution system, or service facility within the next generation. In fact it may be argued that such a goal would be highly undesirable without concurrent major changes in human training, education, work habits, and expectations. A more acceptable approach would be to assume evolution of semiautomated, man-machine systems, with the degree of automation increasing with time. Thus dangerous, dull, repetitive, and other undesirable jobs would be gradually phased out; where necessary, a trained and skillful man would exercise supervisory and judgmental control over many machines in those functions that were too difficult or expensive to automate.* Thus one can visualize a battery of semiautomatic hand-eye-touch machines performing repetitive assembly, inspection, and other operations under supervision by a foreman or overseer. When any machine cannot cope with the unexpected, with breakdowns, or with operations requiring decisions beyond its capabilities, the supervisor takes over control and "helps" the machine past its difficulties. As the autonomous capabilities of the machine are improved by introduction of new techniques, more machines would be controlled by each supervisor.

Major elements of the long-term program should include:

(1) Continued development of visual and tactile sensors and the associated software designed to provide "informational coupling" between manipulators and the external environment.

(2) Development of more dexterous "hands" and tools specially adapted for use with them.

(3) Continued development of software techniques for inspection and quality control, with special emphasis on economy of computational means and simplicity in programming. Special computer languages to facilitate programming may ultimately be required.

(4) Development of software to implement cooperation of several computer-controlled manipulators for fabrication, assembly, materials-handling, and repair tasks.

(5) Development of the interface between man and the manipulator-sensor system, so that supervisory control can be assumed and carried out in a timely and effective manner. Developing techniques in speech recognition may provide an attractive method for this purpose.

*The general concept of the "time-shared" man is not new. In fact every foreman, manager, or captain of industry performs in precisely this fashion, attending to his numerous duties and sharing his valuable talents as the occasion demands.

## IV SOME CONCLUSIONS AND SOCIAL CONSEQUENCES

Much of what is proposed here may be attainable within the next five years. With a set of "building blocks" comprising well-engineered sensors and manipulators, a library of software routines, and a computer language to simplify specification of the required actions, applications can be engineered for a wide range of assembly, quality control, and materials-handling tasks. A subset of these capabilities would also be applicable to service industries. For example, a man-supervised sensor-controlled manipulator could serve as an aide for disassembly and reassembly of engines undergoing repair or maintenance. Or, with special spray or cleaning tools, a sensor-manipulator could be programmed to paint or clean walls or floors. The supervising man could rapidly specify the boundaries of the areas to be treated when he sets up the equipment. In all of the applications, the role of the man is twofold: he programs the system using judgment and skill to maximize effectiveness and he can cope with the unexpected, modifying the program or taking over control of the system.

Large-scale implementation of the proposed automation will be of considerable consequence to our society. On the positive side, the prime emphasis on quality and the elimination of many undesirable and dangerous jobs certainly presents an attractive prospect. On the other hand, technological unemployment, already a significant factor in our economy, could be accelerated. To minimize or eliminate the latter, fundamental changes in our thinking regarding social obligations and problems appear necessary. Since the introduction and acceptance of the new technology will probably be extended over many years, there will be time to evolve a new philosophy of social relationships. Serious consideration ought to be given to many relevant factors and questions, a sampling of which are:

- Permissible economic growth of the nation.

  Should we begin to plan for a leveling off in industrial growth, as inevitably we must? In a steady-state economy, how do we maintain and manage necessary change to prevent stagnation?

- Primary and continued education.

  Should we lengthen the period of compulsory education since we will need better training in the new work force? Should retraining and other continued education for adults of all ages become a right rather than a privilege? How do we provide for those who are extremely hard to educate or apparently uneducatable? Do we deliberately refrain from automatizing some jobs?

- The size of the work week, lifetime length of service, retirement, and so on.

  Should we shorten the work week or reduce the age for retirement or both, thus spreading the available work among more workers? What effects will this have on quality of life and product? Will large recreation-based industries be created to provide new products and services (and of course new jobs)?

It is beyond the scope of this paper to present anything but relatively simplistic solutions to these social problems. Concurrent with the development of the new technology, studies in depth should be initiated to provide timely guidance when the new techniques and equipment become available for large-scale introduction into commerce and industry.

## REFERENCES


1. Agis Salpukas, "Young Workers Disrupt Key G. M. Plant," New York Times, p. 1, (23 January 1971).

2. Walter Sullivan, "Swedes Will End Assembly Lines," New York Times (28 December 1971).

3. Tom Alexander, "The Hard Road to Soft Automation," Fortune (July 1971).

4. L. G. Roberts, "Machine Perception of Three-Dimensional Solids," Optical and Electro Optical Information Processing, pp. 159-197, J. T. Tippett et al., eds. (MIT Press, Cambridge, Massachusetts, 1965).

5. A. Guzmán, "Decomposition of a Visual Scene into Three-dimensional Bodies," Proc. FJCC, pp. 291-304 (December 1968).

6. A. Rosenfeld, Picture Processing by Computer (Academic Press, New York, 1969).

7. R. O. Duda and P. E. Hart, "Experiments in Scene Analysis," Proc. First Nat. Symp. Industrial Robots, pp. 119-130 (April 1970).

8. E. Ejiri et al., "A Prototype Intelligent Robot that Assembles Objects from Plan Drawings," IEEE Trans. Computers, Vol. C-21, pp. 161-170 (February 1972).

9. R. O. Duda and P. E. Hart, Pattern Classification and Scene Analysis (Wiley & Sons, New York, to be published 1972).

10. B. Raphael et al., "Research and Applications--Artificial Intelligence," Final Report, SRI Project 8973, Stanford Research Institute, Menlo Park, California (December 1971).

11. B. Raphael, "Research and Applications--Artificial Intelligence," Final Report, SRI Project 8259, Stanford Research Institute, Menlo Park, California (November 1970).

12. L. S. Coles et al., "Application of Intelligent Automata to Reconnaissance," Final Report, SRI Project 7494, Stanford Research Institute, Menlo Park, California (November 1969).

12. C. A. Rosen et al., "Application of Intelligent Automata to Reconnaissance," Final Report, SRI Project 5953, Stanford Research Institute, Menlo Park, California (December 1968).

14. K. K. Pingle, J. A. Singer, and W. M. Wichman, "Computer Control of a Mechanical Arm Through Visual Input," Proc. IFIP, pp. H140-H146 (Edinburgh, 1968).

15. K. K. Pingle, "Visual Perception by a Computer," in Automatic Interpretation and Classification of Images, pp. 277-284, A. Grasselli, ed. (Academic Press, New York, 1969).

16. K. K. Pringle, "A Program to Find Objects in a Picture," Stanford Artificial Intelligence Project Memo AIM-39, Stanford University (January 1966).

17. G. E. Forsen, "Processing Visual Data with an Automaton Eye," in Pictorial Pattern Recognition, pp. 471-502, G. C. Chang et al., eds. (Thompson Book Co., Washington, D.C., 1968).

18. Patrick H. Winston, "Learning Structural Descriptions from Examples," Proc. MAC Report MAC-TR-76, MIT, Cambridge, Massachusetts (September 1970).

19. K. K. Pingle and J. M. Tenenbaum, "An Accommodating Edge Follower," Proc. Second Intl. Joint Conf. Art. Intl., pp. 1-7 (September 1971).

20. C. R. Brice and C. L. Fennoma, "Scene Analysis Using Regions," Artificial Intelligence, Vol. 1, pp. 205-226 (Fall 1970).

21. A. Rosenfeld, R. B. Thomas, and Y. H. Lee, "Edge and Curve Detection for Texture Discrimination," in Picture Processing and Psychopictories, pp. 381-393, B. S. Lipkin and A. Rosenfeld, eds. (Academic Press, New York, 1970).

22. J. C. Bliss, J. W. Hill, and B. M. Wilber, "Tactile Perception Studies Related to Teleoperator Systems," Final Report, Contract NAS 2-5409, SRI Project 7948, Stanford Research Institute, Menlo Park, California (July 1970).

23. J. W. Hill and J. C. Bliss, "Tactile Perception Studies Related to Teleoperator Systems," Final Report 2, Contract NAS 2-5409, SRI Project 7948, Stanford Research Institute, Menlo Park, California (June 1971).

24. J. W. Hill and J. C. Bliss, "A Computer-assisted Teleoperator Control Station with Tactile Feedback," paper presented at the 7th Annual Conference on Manual Control, University of Southern California (2 June 1971).

25. M. B. Herscher and R. B. Cox, "An Adaptive Isolated-word Speech Recognition System," Conference Record, 1972 IEEE Conference on Speech Communication and Processing, pp. 89-92 (April 1972).

26. J. Dreyfus-Graf, "Sonograph and Sound Mechanics," J. Acoust. Soc. Am., Vol. 22, pp. 731-739 (November 1950).

27. K. H. Davis et al., "Automatic Recognition of Spoken Digits," Ibid, Vol. 24, No. 6, p. 637 (November 1952).

28. P. Derres, "The Design and Operation of the Mechanical Speech Recognizer at University College, London," J. British Inst. Radio Engrs., Vol. 19, pp. 219-229 (1959).