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The Future Trends of Robotics in Industrial Applications

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Abstract

The advent of microprocessor controls and robotics is rapidly changing the face of manufacturing throughout the world. Large and small companies alike are adopting these new methods to improve the efficiency of their operations. Factory Automation, which is in reality by robots, is playing more important role in economic competition and growth. Its core technology, i.e. robotics, is advanced in accordance with the remarkable progress of the computer technology and micro-electronics. Roughly speaking, its future might determine the fate of a national economy. In this paper, the future trends of such robotics and factory automation are described from a point of view of industrial application.

I. Introduction

The history of industrial automation is characterized by periods of rapid change in popular methods. Either as a cause or, perhaps, an effect, such periods of change in automation techniques seem to be closely tied to world economics. Use of the industrial robot along with computer aided design (CAD) systems, and computer aided manufacturing (CAM) systerms characterizes the latest trends in the automation of the manufacturing process. In near future, most of human physical labor would be taken over by "Intelligent Industrial Robots," Such trends in robotics are accelerated by the recent progress of computer technology and micro-electronics, and supported strongly by the countries which aim to increase productivity in industry.

The first industrial robot was supplied in the market from the United States about 30 years ago. In past years, robotics was regarded as a future technology or science. Today, robotics is no longer future technology; it is a technology for the present, and it might determine the economic condition considerably. In addition, the future of robotics must play more important role in economic competition and growth. In Japan, Factory Automation, which is accomplished by robots, has been developed strongly in order to prepare for coming aging society. Since the working population will be decreased in near future, Robotics (as well as micro-electronics) will be the most important key word to keep economic growth and win economic race.

This paper describes such important robotics and developments of factory automation.

II. Role of Robotics in Factory Automation [1]

The Factory automation (FA) spreads rapidly over the world in order to increase productivity in manufacturing. The FA consists of various kinds of techniques such as machining, handling, data acquisition, communication, etc (Figure 1). Flexible manufacturing system (FMS), where machining centers and numerical controlled tools play an important role, represents such various techniques.

The FA is very necessary to increase productivity in small or medium volume production. The processes such as spot welding, arc welding,

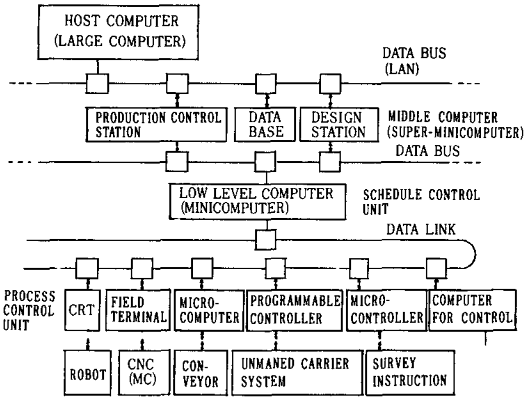

Fig.1. Construction of factory automation system

painting and assembling should be automated in factories. Industrial robots offer a very effective means to meet the demands of flexible automation, because their motions can be easily changed through programming. Motion speed has increased, positioning error of robot hands has become smaller, the reliability of operation has improved, and the price of a robot has declined. In accordance with this progress, industrial robots were initially introduced to perform material handling, then spot welding, arc welding and, painting. Among such processes, assembling has become the most important target of automation by robots, because even in current highly automated factories, 40 to 50% of operators are engaged in assembling operations.

Flexible automations of assembling operations was first realized with simple pick-and-place robots whose working locations were controlled by index mechanical stoppers or by cam drivers. These systems were developed to assemble small electrical or mechanical parts such as gauges, switches and relays. Then computer controlled, teaching play-back type robots-rectangular cylindrical or spherical coordinate robots-were used to assemble rather complicated parts like mechanical parts of tape recorders, video recorders, or floppy disc drivers. Very recently these robots have been introduced in the final assembling lines of automobiles in which complicated motion of large and heavy parts is required.

In spite of these great progress, there still exist difficulties in flexible automation of assembling operations which can be attributed many factors as follows. The average operating capability of the present advanced robot is about 60-80% of that of a human operator, and the price of a robot and associated devices such as part feeder and parts magazine are still too expensive to justify economically in many cases. Furthermore, assembling operations often require accurate positioning of a part assembled against the main body in spite of the weak, less rigid structure of the robot. Changing of robot motion through teaching or reprogramming is time consuming and some assembling operations require both delicate and intelligent motion of the robot hand. When these difficulties are overcome, the degree of automation in assembly operations will increase significantly. In order to promote this trends, further technical advancement are required for the hardware, software and associated devices. These include the development of quickly moving robots like direct driven robots, cost-down of robots by using more of them, re-designing robot structures, development of fast vision sensors, force sensors, tactile sensors and software controlled remote center compliance devices.

III. Present Trends of Industrial Robots

1. Present Situation of Industrial Robots [2]

Robots used today are primarily machines with manipulators that can easily be programmed to do a variety of manual tasks automatically. The robot consists of the following:

* One or more manipulators (arms)
* End effectors (hands)
* A controller
* And, increasingly, sensors to provide information about the environment and feedback of performance of task accomplishment.

The motivation for most current robotic development is to achieve the following goals:

* Increase productivity
* Reduce costs
* Overcome skilled labor shortages
* Provide flexibility in batch manufacturing operation
* Improve product quality
* Free human beings from boring and repetitive tasks, or operations in hostile environments.

As indicated in Table 1, the Japanese are the world's largest user of robots. Of the 1982 estimate of 55,000 robots in operation in the entire world, Japan had well over half, while the United States had less than 12%. Table 2 presents the principal users of industrial robots in Japan. It appears that the electric/electronic industry is the largest user of robots. Less than 1% of industrial robots were utilized outside of manufacturing. Table 3 shows the percentage of use of robot in Japanese production process. It is apparent that assembling field dominates the use of robot. Table 4 shows a supply of industrial robots in Japan. Japanese industrial robots are classified by their type in Table 6.

2. Research Activities in Japan [3]

Regarding R&D activities of universities, approximately 70 universities (private and public), are conducting research activities, and there are many cases of inter-faculty and interdivision research competition in a single university. Concerning the research and development of robotics by public research institutions, 7 national research institutions and 17 prefectural institutions are engaged in research. In addition, there are many cases in which R&D activities are conducted with the cooperation of enterprises, universities and public research institutions.

As for the content of each R&D activities, priority is given to efforts for increased sophistication and speed, cost reduction, and improved

Table 1. Industrial robots in operation

1. Japan	31,900
2. United States	6,300
3. West Germany	4,300
4. Sweden	1,500
5. Italy	1,100
6. France	1,000
7. United Kingdom	1,000
8. Belgium	300
9. Canada	300
10. Poland	300

*Approximate number as of the end of 1982
(Manual manipulators and fixed-sequence robots are not included.)
Source: Worldwide Robotics Survey and Directory (1983)

Table 2. Principal users of industrial robots in Japan (End of 1985)

Electric/Electronic Industry	35%
Automobile Industry	16%
Others	29%
Exports	29%

*Rate based on price
Source: Japanese Industrial Robot Association (1986)

Table 3. Percentage of robot usage by production process

Process	Rate
1. Assembly	40%
2. Cutting	11%
3. Loading and unloading	10%
4. Welding	6%
5. Resinating	6%
6. Press	6%
7. Inspecting	8%
8. Others	14%

Source: Japanese Industrial Robot Association (1986)

Table 4. Production of induustrial robot in Japan

Year	Production Volume (Sets)	Production Vaule (¥bililon)
1983	30,224	183.8
1984	40,080	268.1
1985	47,820	302.3
1986	48,500	370.0
1990 (Estimate)	324,800	694.0
1995 (Estimate)	537,500	1360.0

Source: Japanese Industrial Robot Association (1986)

Table 5. Production of robots by type in Japan (1985)

Type	Production Value (Sets)	
Manual Manipulators	1,043	2%
Fixed-sequence Control Robots	13,265	27%
Variable-sequence Control Robots	6,195	13%
Play-back Robots	14,066	30%
Numerically Controlled Robots	10,033	22%
Intelligent Robots	2,948	6%

Source: Japanese Industrial Robot Association (1986) reliability and precision of the technology that is currently used for industrial robots. Concurrently, efforts are being exerted in research related to such sensory functions as visual and tactile senses, mobility functions, learning functions, and others.

IV. Design Issues of Industrial Robots

1. General Issues [4]

Robots are required to have much higher mobility and dexterity than traditional machine tools. They must be able to work in a large reachable range, access crowded places, handle a variety of workspieces, and perform flexible tasks. The mechanical structure of robots, however, significantly departs from traditional machine design. A robot mechanical structure is basically composed of cantilevered beams, forming a sequence of arm links connected by hinged joints. Such a structue has inherently poor mechanical stiffness and accuracy, hence is not appropriate for the heavy-duty, high-precision applications required of machine tools. Further, it also implies a serial sequence of servoed joints, whose errors accumulated along the linkage. In order to exploit the high mobility and dexterity uniquely featured by the serial linkage, these difficulties must be overcome by advanced design and control techniques.

2. Kinematics [4]

The serial linkage geometry of manipulator arms is described by complex nonlinear equations. Effective analytical tools are necessary to understand the geometric and kinematic behavior of the manipulator, globally referred to as the manipulator kinematics. This represents an important and unique area of robotics research, since research in kinematics and design has traditionally focused upon single-input mechanism with single actuators moving at constant speeds, while robots are multi-input spatial mechanism which require more sophisticated analytical tools. Usually, homogeneous transformation (4x4 matrix) is used as powerful tool to analyze kinematic behavior of industrial robots.

3. Control

Serial linkage robot arm is a highly nonlinear system with complicated interactions between the each joints. These interactions represent gravitational forces dependent on positions of the arm, reaction forces due to accelerations of other joints, coriolis and centrifugal forces. In addition, there are parameters dependent on the variable payloads carried by robots driving in manufacturing process. But, such interactions are suppressed by reduction gear with large ratio in "Present Industrial Robots," and then conventional PID controller based on a linear arm model neglecting interactions is used widely. There are not so many serious problems at present.

In the near future, the remarkable progress of hardware enables us to use direct-drive arm (without reduction gear) in stead of conventional arm with large gear ratio. Since, in direct-drive arm, mutual interactions are prominent compared with other robot arms, conventional PID controller cannot make the most of good characteristics of direct-drive arm. The problem of handling such large interactions is imposed on the side of control research nct that of hardware research. In order to realize the on-line computer control for such direct-drive or highly nonlinear robot arm, the follwing two points are the key problems for designers to choose a control law:

(1) Avoidance of complex computations for the nonlinearcompensation.
(2) Robustness of the manipulator control to the unknown parameter variations or modeling ambiguities.

To overcome the above difficulties, the following control methods
(a) Adaptive Control [5] [6]
(b) Nonlinear Control [7]
(c) Variable Structure Control [8] [9]
(d) Learning or Iterative Control, etc. [10]
are proposed. In near future, classical PID controller would be replaced by the above control method.

4. Communication

Robots are required to interact much more heavily with peripheral devices than traditional numerically-controlled machine tools. Machine tools are essentially self-contained systems that handle workpieces in well-defined locations. By contrast, the environment in which robots are used is often poorly structured, and effective means must be developed to identify the locations of the workpieces as well as to communicate to peripheral devices and other machines in a coordinated fashion.

Recently, "Manufacturing Automation Protocol (MAP)" has been proposed as a common protocol for LAN in factories. Using this "MAP", robots, peripheral devices and host computers are linked physically in order to communicate each other. At that time, robots must exchange informations with sensors (vision, etc.), peripheral devices and host computers through common language.

V. Future Trends of Industrial Robot

1. Manipulator and Actuator Design [2]

To achieve the higher speeds, flexibility, accuracy, efficiency, and dexterity that is desired in future robots, additional research in manipulator arms are needed. For large manipulators and precision work, joint and arm structural flexibilities can be a problem. Therefore, stiff, but lightweight arms are desirable to minimize this problem and to aid in increasing speed. However, as variable compliance in different directions is often desirable to provide the "give" needed for inserting parts and other assembly operations, unique design approaches may be required.

At present, actuators are one of the more problem-prone areas of robots. In addition, actuator efficiencies are in the order of one-tenth that of human musculature. Smaller, more reliable and efficient actuators and drive mechanisms, with high load-to-weight ratios, are needed for the high-speed, lighter-weight robots of the future.

For greater dexterity and less intrustion into the work zone, it is also necessary to understand the mutual interdependence of end effector and manipulator kinematics. Also, research on micromanipulators is needed for applications to microelectronics and biology.

A unified theory is needed on how to design an arm for smooth universal movements, satisfaction of functional requirements, and to provide the required load capacities throughout its motion spectrum. A standardized approach to performance measurement and evaluation is required to enable comparison of robots not only in such factors as working volume, load capacity, and reliability, but also in aspects such as speed, smoothness, and accuracy throughout their operating range.

2. Control

An important area of control not yet solved is control of structurally flexible manipulators.

Most of the industrial robots used today attain precise positioning of the end-effector by controlling their joint angles. Consequently they are designed so as to enhance their mechanical rigidity at the expense of lightness. Large weight, however, introduces limitations in terms of speed, energy consumption and maneuverability. Therefore it is important to design light weight manipulators whose dynamic response is not affected by its structural flexibility. In this case, there lies a severe problem, that is, the vibration of the arm inevitably occurs and may make stability of the whole system worse. This undersirable vibration must be eliminated by highly sophisticated control algorithm.

There have been a number of papers presented on this problem. In the early study by Book [11], mathematical model of two-link flexible arm is derived and three control methods are proposed: two of them are based on the joint angle measurement and the other utilizes the arm deformation signal as well. It is not possible to conclude, however, that this control scheme with feedback of the arm deformation results in superior performance due to sensitiveness to perturbations of the system parameters.

Fukuda [12] proposed a new control method and confirmed its validity by experiments: the lower three vibratory modes are directly computed from the outputs of strain gauges attached to the arm body and state feedback technique is used.

Since strain gauges can detect only local distortion of the arm, there remains a problem of accuracy and overshoot. Cannon[13] solved it by introducing optical position sensing of the end-effector. In this case, however, achievement of stability becomes very severe and robustness of the whole system cannot be so high.

Harashima[14] proposed a new strategy for a single-link flexible arm. Control purposes to be accomplished are as follows:

(1) Fast positioning of the end-effector without any overshoot or vibration to be attained.
(2) Dynamic response of the arm to be kept constant in spite of parameter change such as payload variation.

In order to realize these purposes, the end-point position sensing by CCD (Charge Coupled Device) camera and adaptive control method are introduced. Since the transfer function of the flexible arm is nonminimum phase, the adaptive controller is designed based on AR (Autoregressive) model with dead time in order to avoid unstable pole-zero cancellation.

The control of redundant-axis manipulators, needed to provide additional maneuver capability, is an area in which little is known about ideal soutions.

Design of control systems for fault tolerance will become particularly important as robots become more autonomous.

Finally, lack of suitable strategies for control of multifingered hands is still one of the principal factors retarding design of dexterous hands.

3. Vision Techniques [2]

In the industrial manufacturing arena, to circumvent that the workpiece be in a prescribed position and orientation for the robot to operate upon it, sensory systems can be employed. Vision provides perhaps the most flexible approach to avoid all the fixturing that would be required to achieve a fixed pose. Vision can also reduce the accuracy requirements of manipulator by making real-time adjustments practical.

At the current state of the art, additional research in recognition and geometric representation is needed. As greater capability is desired, three-dimensional vision combined with world models and spatial reasoning will become important. Current three-dimensional research in vision systems center on the use of range finding, structured light, and binocular vision systems. Further out, research is required in the analysis of image sequences (optical flow, shape from motion), intrinsic image analysis (determining shape from a single image by disambiguating the response to light), and improved methods to recognize objects in clutter, such as picking an object out of a bin.

One important research area in vision is how to improve the speed of visual processing. This includes research in computational elements structured for visual processing, which includes parallel-processing CPUs, and special chips for edge finding, Fourier analysis, and so on. Even more important is fundamental algorithm development.

4. Tactile and Force Sensing [2]

What is needed is better use of contact-sensing data. This includes better resolution in touch and force sensing, as well as better control strategies which make use of such information. An important result could be the ability to recognize parts and to determine their relative position and orientation by such methods.

5. Intelligence

Intelligence is very important, but the research theme of intelligence is not so clear. Then, so-called intelligent robot stands for typical research of this field. One of faculties which it must possess is to understand its environment by the use of models.

Object recognition using tactile image array sensors is reported in [15). The objective of this research is to develop an object recognition system through the combination of 2-D tactile image array and visual sensors. A video camera is used to acquire a top view image of an object and two tactile sensing arrays mounted on a gripper are used to detect the tactile information about the lateral surfaces of the object. 3-D reference object models are established as a decision tree, and recognition of unknown objects is accomplished through measuring and comparing input object features hierarchically with these of the reference objects associated with the decision tree.

VI. Future Trends of Factory Automation [1, 16]

Even though flexible automation of various manufacturing processes is now becoming common, it must be said that automation of operations is still limited to rather application in a factory setting, which does not result in much profit. The situation can be compared to several highway systems, which are connected by slow-moving country roads. In order to obtain high productivity as a whole, there is need to coordinate all the manufacturing activities in cooperation with each other. Efforts to realize the whole intergration of all the manufacturing activities which can be called factory automation has just started in various industries such as automobile, business machine and computer peripheral machine industries in Japan.

The situation of the factory automation are schematically pictured as shown in figure 2 in which two different kind of flow, are represented by arrows and solid lines respectively. Here manufacturing starts from machining operations of raw material, goes to assembling and inspection, and finally ends at the rack station for stock of the finished products of the customer. In order to keep the material flow in a factory well in the very rapidly changing demands of the customers, we have to develop proper control algorithms in the information flow. These are:

(1) Production and material flow control algorithms,
(2) Quality control algorithm,
(3) Maintenance control algorithm.

Once these algorithms are established, then one can construct hierachical information network shown in figure 3. In the network various control units on the shop flow such as numerical controllers, programmable controllers and machine control gauges in each manufacturing line or station from the networks at the lowest level for operation state of the manufacturing facilities, monitoring of the operation state of the manufacturing facilities, monitoring of the amount of workpieces in buffers and gathering of the inspection and test data. A network for the own line or station is controlled by the personal computers for each purpose. The personal computers are connected by mini-computers to form the network at the second lowest level for maintenance, production control and quality control in a division

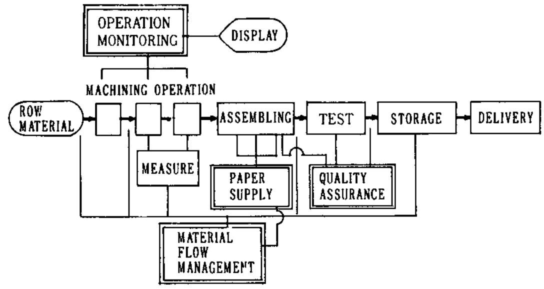

Fig.2. Information system in a factory

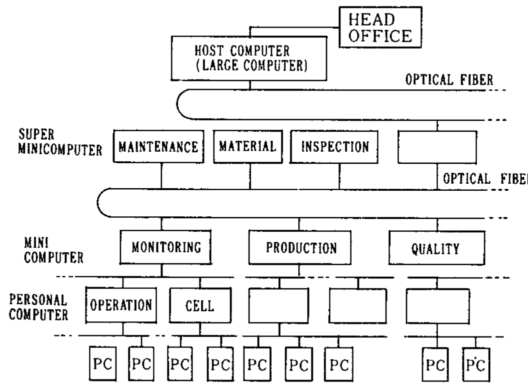

Fig.3. Information network for computer integrated manufacturing

of the factory respectively. Then the next higher level of communication network is formed to link these mini-computers in the factory together, the super-mini-computers for data gathering of operations, maintenance and quality control and with the control computer at the headquarter can communicate at the highest network level.

At present some advanced companies in Japan have established the concept of factory automation above mentioned, and started to anstall the information network at the lowest level, or the shop floor level, and to develop many aperation softwares working on the shop floor level such as operation control and management, part delively, quality control, and failure diagnosis. After mast operation softwares are developed, then efforts will be directed to form the information network at the second lowest in the buttom-up manner.

VII. Conclusion

The future of factory automation is bright and quickly approaching. Robots, as we know them now, may still exist, but their character is likely blend with other machines as "manipulation" becomes a miner element in the definition of the future robot. Elements of sensors, such as touch, vision, and range, or artificial intelligence, may be shared with so many other machines that distinction could become unwarranted. the trem "industrial robot" may then become synonymous with flexible manufacturing equipment, or programmable function machines.

The topics of this paper are chosen in accordance with the author's interests. Important topics such as pure intelligence, programming, task planning, mobility and so on are omitted here. Among such topics, the large-scale national research and development project "Advanced Robot Technology" of Japan is expected for high technology. This project was initiated in 1983 with the Japaness government taking the lead. In this project, research and development will be conducted with a total budget of approximate ¥20 billion during an 8-year period up to 1990 by combining the capabilities of both the industrial, academic and government sectors.

Robotics which might control the fate of a national economy becomes more important as the computer technology and microelectronics make progress year by year. And that, robotics provides innumerable attractive research themes for engineers and scientists.

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