Robots in Japan: Present and Future

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The world-wide slackening of business activities appears to have also slowed the pace of the industrial robot business. It is often said that we are now entering an epoch where the industrial robot is to be succeeded by the "service robot". The designation "service robot," however, still remains to be clearly defined. As yet, the image evoked by this term varies very widely from person to person, in both the external appearance and the technological elements that constitute such a robot.

CONCEPT OF THE SERVICE ROBOT

The general concept of "robot" can has its origin in the innate human desire to be able to "wield colossal force, to fly through air, to travel through water and through earth," or otherwise, "to command a substitute that would replace one like a servant in performing trying jobs." Such concepts have since ancient times spurred the human imagination to conceive "automatons" and performing dolls. Subsequent advances in science and technology have actually come to create automated machines that provide an increasing diversity of functions. The term "robot" is derived from the Czech "robota", meaning "worker" and was coined by Karel Czapck in his play "Rossum's Universal Robots."

Linking this concept of "worker" to "production" has resulted in what we know today as the industrial robot, which can take the form of manipulators that have degrees of freedom comparable to the human arm. These robots possess superhuman capabilities in terms of force and power, speed, reproducibility, and untiring effort through long hours of monotonous repetitive work. With these capabilities the robots can enhance productivity and rationalization in manufacturing operations.

Other robots are not necessarily linked directly to production. Compared with the industrial robots, which enhance manufacturing productivity and productive rationality, these other robots provide functions of a higher level, and can be considered to answer the call mentioned earlier for "a substitute that would replace one like a servant"—a human desire that still today continues to inspire our imagination. These are the functions that are to be performed by this new generation of "service robots."

A definition like this still encompasses a vast range of aspects that could be assumed by these service robots. The concept of "service" itself covers an immense variety of activities. Moreover, the degree of satisfaction felt by the client from the service received from robot would also differ widely from person to person and from organization to organization, according to his or its sense of values, and depending on the nature of activities performed by the robot, and on the circumstances under which the service is furnished.

Taking all these factors into consideration, we shall here consider the "service robot" to be a generic term covering all robots that are not for industrial use, i.e. that are not intended for rationalizing production at a manufacturing site.

Two classes of robots can be conceived to comprise service robots as defined above:

Mr. Asami was one of the plenary speakers at ICRA94 in San Diego. In the coming issues of R&A look for articles by the other featured speakers: Mr. Joeseph Engelberger, Chairman of Transitions Research Corporation and founder and first president of Unimation Corporation; Dr. Rolf-Dieter Schraft, director of the Fraunhofer Institute for Manufacturing, Engineering and Automation in Stuttgart, Germany; and Col. Richard Satava of Walter Reed Medical Center and ARPA.

Class A. **Robots to replace human beings at work in dirty, hazardous and/or tedious operations**
- Operations in arduous environment (e.g., in high temperatures, vacuum, underwater, radioactive environment)
- Fire fighting (fire extinction, life saving)
- Police applications
- Military applications
- Architecture (inspection/maintenance outbuildings/ structures)
- Publicity (attracting customers etc.)
- Entertainment (appearance in films)
- Housework (floor sweeping)

Class B. **Robots to operate on or with human beings to alleviate incommodity or to increase comfort/pleasure**
- Medicine (patient care)
- Guiding the blind
- Entertainment (use in gaming houses, in amusement parks)
- Housework (table service)

The operations/services to be performed in the foregoing activities might in some cases be suited to robots presenting an appearance similar to human beings, but much more often, the robots would assume an entirely original shape to match the specific function for which they are intended.

FACULTIES EXPECTED OF SERVICE ROBOTS

Service robots are distinguished from industrial robots by the following faculties which permit effective and unobtrusive operation in the human living environment:

Mobility. To possess the means of displacing itself in the manner most suited to the envisaged activity (wheels, legs, suction cups, adhesive pads, friction, flying, swimming). Mobility is arguably the most indispensable faculty for a service robot.

Portability. To be compact and lightweight, and preferably equipped with a self-contained energy source.

Operating ease.To be provided with an interface with the human operator/client that will present the least difficulty to him (e.g. ultimately to function in oral conversation between man and machine).

Sensing/learning/judging function (artificial intelligence). To be equipped for operations in unfamiliar environments with scanty information on external conditions, under conditions varying with time, and subject to measurement error.

Adaptability. Suited for varying operations and environmental conditions; the ideal all-round robot, which cannot be easy to realize, might possibly be approached through the development of multiple single-function robots, which function in concert.

The ultimate target would be a robot that possesses faculties approaching that of human beings. Leaving such an ideal robot as a goal for the future, intermediate robots that only satisfy a limited selection of the most essential functions should still find good use in human society.

R&D IN JAPAN ON SERVICE ROBOTS

In Japan, research and development efforts are under way at government, university and industrial institutes on the technological elements required to realize service robots, and which are directed principally toward improvement of performance and toward enhancing practical applicability in such aspects as mobility, manipulation, sensing, and artificial intelligence.

A large-scale national project initiated in 1993, the "Research and Development of Micromachines", has particular relevance to the development of technological elements for service robots. This project is directed toward the realization of units capable of operating in minute spaces that preclude access to manual operations. One means to accomplish this goal is to combine multiple micromachines that function together to constitute an integrated large-scale multiple-function system.

Another direction taken in service robot development is toward limited-purpose robots to serve such specific purposes as guiding the blind, patient care, floor sweeping, building/civil construction work, and inspection operations. To this end a notable national project was carried out in the period 1983-1991 on "Advanced Robot Technology" (research and development of robots to function in extremely arduous environments). The operations envisaged were maintenance of nuclear plant interiors; maintenance of offshore structures; and fire fighting in petroleum complexes (first-response).

Next-generation robots possessing all the faculties requisite for any of the operations cited above are still quite a long way off. In the mean time, limited-faculty intermediate robots providing a restricted selection of the most requisite functions should still prove to satisfy certain market needs.

Some other more complex needs might be satisfied by a combination of robots functioning in concert.

While not forgetting our ultimate aim of realizing an ideal multiple-faculty service robot approaching the human being in versatile capability, as a manufacturing enterprise, we consider a practical and important step to be the development of limited-faculty service robots corresponding in sophistication to animals of lower order. Such intermediate robots should be capable of meeting specific individual needs of the social environment while satisfying the economic requirements of price and operating cost. They should collectively serve also in generating and developing a larger market for service robots.

THE JAPANESE MARKET FOR SERVICE ROBOTS

As yet there exist no statistics covering the production specifically of service robots in Japan. What might serve as a reference are the values of industrial robot deliveries to non-manufacturing industries appearing in the statistics published by the Japan Industrial Robot Association. In the period between 1978 and 1992, the deliveries marked a prominent peak in 1986 (Figure 1). The "non-manufacturing industries" com-

Long-term market survey covering non-manufacturing industries

	Billion	Yen
	1995	**2000**
Agricultural Industry/Stockbreeding	5.9	18.5
Forestry	4.6	5.6
Marine Products Industry/ Ocean Development	15.4	39.2
Civil Construction	31.1	72.1
Mining Industry	3.4	5.3
Warehousing & Transportation	18.6	35.7
Commercial Business	4.8	6
Gas Company	1.4	2.8
Water Service Industry	2	3.6
Electric Power Industry	3.2	6.3
Nuclear Power Industry	11.9	15.2
Communication Industry	0.8	1.7
Space Industry	7.5	11
Medical Welfare	3.8	12.1
Waste Treatment	2.1	8.9
Fire Fighting/Prevention of Disasters/Guarding	4.6	46.3
Education	2.2	4.6
Research Development	3	3.7
Other Service Industry	5.2	10.8
Total	**131.5**	**309.4**

prise in large part electric power companies, including those utilizing nuclear power, and consequently the variations of demand fluctuate widely with the peaks and valleys in the program for nuclear power plant construction. For non-manufacturing industries excluding electric power, the total value is as yet trivial, but the trend is clearly toward steady increase.

A long-term market survey covering non-manufacturing industries conducted by the Japan Industrial Robot Association in 1990 (See the Table) estimated the demand for industrial robots to attain 131.5 billion in 1995 and 309.4 billion in 2000. These estimates were made in the period preceding the decline in business activity. The actual deliveries recorded in 1992 only reached around 6.7 billion. Nevertheless it cannot be denied that there exists a fast growing market for such robots.

Factors favoring the marked demand for service robots include shortages in the simple labor market, created by the popular trend toward higher education levels, shortages in the aging specialized labor market, created by the increasing ages of highly skilled technical personnel, and trends toward replacing manual by robotized operation in hazardous work. Negative factors affecting the service robot market include insufficiently rapid development of requisite sensors and of their judgment faculty, and high cost.

A promising future market for service robots to be used in different applications is civil engineering, for which a multitude of robots have already been successfully developed. In this field, the declining current business activity is counterbalanced by a persistent shortage of labor, which encourages expectations of growing demand for robotization. Another hopeful domain is medical care, with the rapidly growing number of the aged population—which has induced the creation of businesses in home care service for patients, and which is sure to accelerate the demand for robots to aid in such care. In the manufacturing industries, slackened business activity has delayed replacements of production equipment, and the consequent extension of equipment/structure service life, combined with the call for enhanced safety in plant operation, has augmented the demand for maintenance robots.

MAINTENANCE ROBOTS

Maintenance robots are intended for worksites involving hard, dirty and dangerous operations, and which consequently are increasingly shunned by workers.

Since safety of workers is the responsibility of Japanese employers, they have been led to spend considerable sums in equipment and devices for ensuring work safety. This has raised the demand for robotizing the operations. A particular requirement of such maintenance robots is that they must be capable of displacing themselves over the large installations and equipment they are to cover.

Maintenance operations comprise the steps of inspection, judgment of current condition, and treatment/ repair operations. A universal robot single-handedly capable of covering all three steps would not necessarily provide the optimal solution, since not all cases call for carrying through the operations down to treatment/repair state. Consequently, a combination of robots specializing in the individual steps and operating together should be considered the most realistic and practical solution.

In current practice, after the inspection of building structures the assembled inspection data is submitted to human judgment to determine the soundness of the structure, and to judge whether treatment or a repair operation is called for. This judgment faculty would not justify robotization, since the necessity of actually performing a treatment/repair operation should seldom occur. Furthermore, there would exist a vast variety of operations to be scanned and factors to be considered in order to select the most suitable operation.

However, an operation that should well justify robotization is painting of buildings and large structures. This is an operation that is largely standardized and is subject to little variation according to inspection results.

Also promising is the inspection of large structures, in which robotization would dispense with the installation of scaffolding. The economies brought in terms of time and cost would permit increasing the frequency of inspection and enhancing the safety of the structure.

The current development of compact, lightweight inspection robots to permit their application to operations in arduous environments precluding human approach—high temperature/pressure, vacuum, underwater, radioactive environment, etc.—is already contributing to progress in the diagnosis of plant soundness.

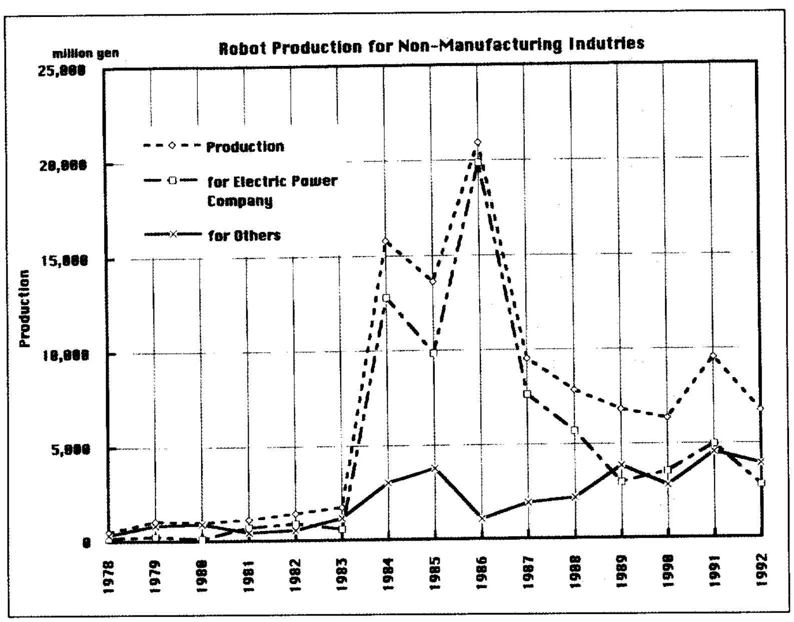

Figure 1 Robot production for non-manufacturing industries.