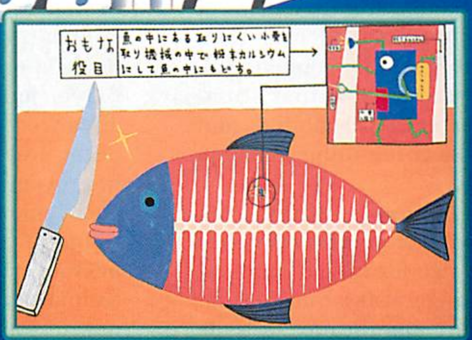
Micromachine
マイクロマシン

Dec. 1996



No. 17

MICROMACHINE CENTER

Essay

Micromachine Fascination

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The President, The University of Tokyo

Research on micromachines has been rapidly extending. This is owing in part to the efforts of the Micromachine Center, and in large part to the volition of researchers and enterprises who are promoting the Industrial Science and Technology Frontier Program "Micromachine Technology". In addition, we cannot overlook the profound fascination of the concept of micromachines that has attracted people in various fields.

What is that fascination? It cannot be the mere smallness. Size reduction has been a long-standing economic virtue because it saves materials and energy and improves the efficiency of transportation and storage, thereby leading to cost reductions.

However, the micromachine is not simply an extension of size reduction. It is not quantitative improvements such as in efficiency that attract us to micromachines. The fascination lies in changes in quality, in technologies that we have never seen before. Such technologies attach an absolute significance to scale.

Let us think about manual work. The word "handy" bears an abstract meaning for convenience. It originally means the size fit for handling or use. A "handy" thing measures about several centimeters, and can be carried or manipulated by hand. A thing over 10 cm is not so easy to handle with a single hand, and we may have to hold it in both hands. A much larger thing of about 1 m has to be held with both arms.

Similarly, there are various handling methods for smaller things. We put pencils and cigarettes between fingers. Things smaller than several millimeters may be picked up with our fingertips. Ball-like things measuring less than 1 mm are not easy to pick up, but they can be collected by pressing finger tips and lifting with the adhesive force.

Thus, human beings can handle from particles of 1 mm or smaller up to large objects over 1 m in size. This is an amazing operational flexibility compared to man-made machines such as robots. The first stumbling block for a robot designer is this flexibility, and it is almost impossible to make a handling machine that has human-level flexibility.

The operational flexibility of human beings is not the only meaning of this episode. It suggests another important fact that the object size for human manual operations is restricted to a range of 0.1 mm to 1 m. This is the basis of the absolute significance of scale mentioned before.

Modern mechanical technologies have paid most attention to objects of greater scale. More power, higher speeds, and higher efficiency have been the virtues of modern mechanical technology, and from the early stages of technology, enlargement has been a means to get these virtues beyond the capability of humans. Academically, technology systems for objects measuring over 1 m to huge scales have been obtained on the theoretical foundations of structural dynamics, thermodynamics, fluid dynamics, and the theory of mechanisms. This contributed much to developing the rich society we enjoy today.

On the other hand, the handling of smaller scale objects has not progressed so satisfactorily. As mentioned before, sporadic efforts have been made for cost reduction and improvement of accuracy in precision processing, precision measurement, and fine-control precision machinery. However, there has been no vision looking into the vast territory of the microscopic world that extends ever smaller beyond the lower limits of human manipulation.

Micromachine technology is not merely microscopic technology; its fascination lies in this unexplored micro world waiting for establishment of whole new systems of technology. In this world, we often find cases where familiar precepts of technology no longer had true. Specifically with individual elements, the so-called scale effects govern much in the micro world. They range from material defect effects to quantum effects, but all are insignificant in the macro world in which we live. Because of space restrictions, it is no longer sufficient to think of a phenomenon solely from mechanical or electrical logic, but instead field-fusion approaches are indispensable.

Many universities, research institutes, and enterprises in many countries have already started study to find new possibilities of micromachines in various application fields, because the importance of these fields is predicted to increase. These fields of application include medical treatment and life sciences where advanced technologies are being developed at high pace, and socially critical regions such as security improvement by advanced system maintenance. As such, micromachines fascinate us not in particular fields of application, but in the latent ubiquitous micro world in various fields, as a way leading to new technology systems and new theories that open up a new technological world.

Bio-manipulations using Micromachine

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Abstract

Methods for the manipulations of biological cells and DNA using micromachine technology is being studied in our laboratory. In particular, a technique for the stretching and positioning of a single DNA molecule on a substrate is investigated. Its applications are not limited for a new DNA sequencing method by dissecting arbitrary part of the DNA strand, but also found in various area, for instance, basic researches on molecular machine through a space- and time-resolved observation of the action of enzymes on a DNA strand, or molecular machining using the enzymes as the tools.

The unit component of a living organism is the cell, which usually measures from several to several tens micrometers. A cell contains a full set of nanometer-scale apparatus, including the enzymes for reproduction and metabolism, and DNA as the information storage device. The apparatus are not randomly packed inside the cell membrane, but form ordered structures, supported by substrates (membrane structures) and frames (cytoskelton), which are optimized so that successive reactions take place in highly efficient manner. In contrast, human attempts to simulate bioreactions are, to date, not so sophisticated. We just prepare a homogeneous solution in a test tube, and rarely try to control the position and motion of the individual molecule, nor to directly manipulate a specific part of a specific molecule.

Take an example of reading genetic information. At a single trial of electrophoresis, up to about several hundreds of DNA bases can be analyzed. To deal with a longer DNA, it must be cut down to segments, then the base sequence on the segments is analyzed and the respective segment informations are reassembled

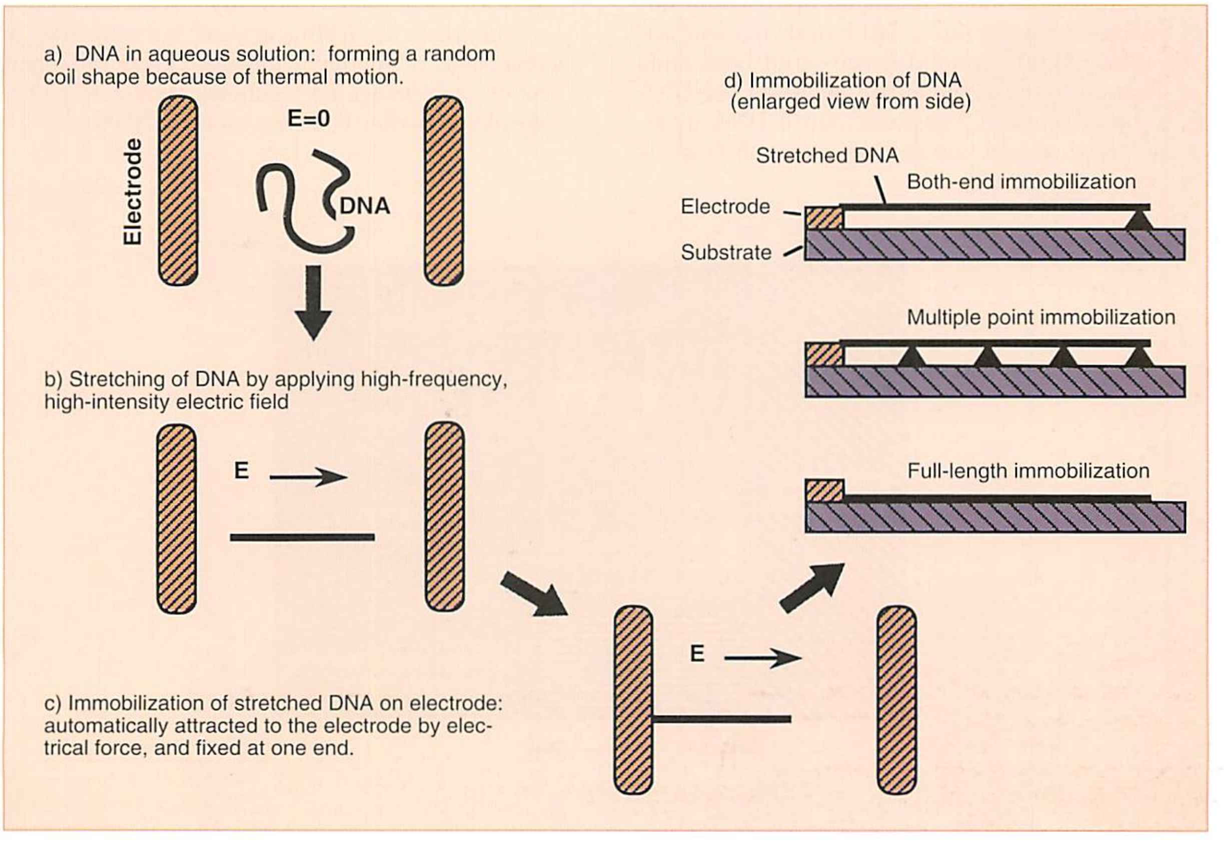

Fig. 1 Stretch-and-positioning of DNA by electrostatic field

into the entire long string of DNA. The reassembling process is necessary because all the segments are diffused and mixed in solution at the instant when they are reduced from the original DNA strings by enzyme. This process may be analogous to reducing a book on a shredder before reading it. It would be better by far if we can fix individual DNA molecules on a substrate and cut them into pieces from the end.

Such manipulation of individual molecules used to be a mere fantasy until about just a decade ago, but recent advancements in micromachine technology made it feasible. The technical seeds of such micromanipulation are: 1) micromachining technology, 2) precision positioning, 3) molecule visualizing technology, 4) manipulation technologies such as scanning probe and laser manipulation, and 5) molecular manipulation technology that controls position and orientation of molecules and fastens them.

We have been studying mainly bio-manipulation technology in which molecules and cells are manipulated using an electric field. Figure 1 shows schematic diagrams of the technology we developed to stretch DNA molecules and fix them on a substrate using an electric field. DNA is a string of polymers of 2 nm in diameter and the length is 1 μm per about 3000 base pairs (3 kb). DNA takes randomly coiled shape in water, rolled up by Brownian motion (Figure 1 a). In a high-frequency, high-intensity electric field, the molecule is stretched (b), attracted towards the electrode, and positioned to the electrode on one end (c). With appropriate immobilization technologies, the string can be fixed to the substrate on both ends or at several points on the molecule, or over the entire length (d). Different immobilization technologies are used for different purposes, for example, full-length immobilization to obtain tight immobilization, and both-ends immobilization to make the entire length of the DNA ready to be affected by enzymes. Once DNA molecules are stretched and immobilized on a substrate, it is easy to access a desired position on a desired molecule.

To stretch and position DNA, a high tension electric field of over 1 MV/m is used. Use of such a high-intensity electric field in water is impossible without the use of the micro electrode system, having a high surface-to-volume ratio and excellent heat dissipation efficiency. With the use of a macro electrode system, the solution is instantly evaporated due to the heat produced by Joule effect. This is an example where the scaling law of micromachines works favorably.

Figure 2 shows λ-phage DNA (48 kb, 16 μm long) mechanically scratched to cut by the tip of a scanning atomic force microscope at four positions. This method will make it possible to analyze the DNA molecule by sequentially cutting it from the end.

Other ongoing studies in our laboratory include analysis and utilization of interactions of enzymes and DNA, for instance, observation of the dynamics of sliding motion of an RNA polymerase along a DNA molecule, and DNA dissection by pressing DNase (DNA cutting enzyme) labelled fine particle against stretched DNA. The latter is a good example that shows the potential of enzymes as a tool for molecular machining.

Viewing enzymatic reactions through these studies, it seems to me that the process where a molecular enzyme catches on and reacts with the substrate (the object of the enzymatic reaction) is the ultimate image of a micromachine. The relative position of the enzyme and the substrate must be controlled so that the enzyme can bite on the substrate properly, just like we design machines so that the parts do not interfere with each other. Certainly researches on molecular machines in living organisms will give much suggestions to micromachine design. In the other way around, micromachine technology will also make considerable contributions to such researches.

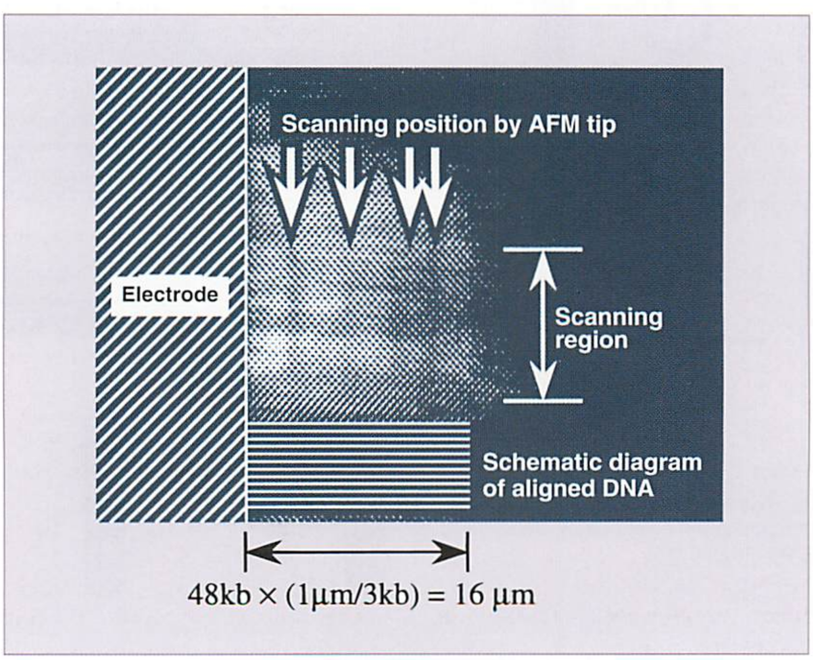

Fig. 2 Dissection of DNA molecule by AFM tip

Summary of Report on "Study for the Influence on Industry and Society Structure by the Introduction of Micromachine Technology"

The titled research, commissioned by The Japan Machinery Federation to the Micromachine Center, was conducted in fiscal 1995 by a committee led by Chairman Fumio Kodama, a professor at the Research Center for Advanced Science and Technology, The University of Tokyo, and Vice Chairman Tokio Kitahara, a senior researcher at the Mechanical Engineering Laboratory of the Agency of Industrial Science and Technology. The report was completed at the end of March 1996.

This research, aiming to predict the influence of practical applications of micromachines upon industrial activities and social life in the 21st century, surveys seeds of micromachine technology, needs in industries and the society, and cases of technological innovations, tried to develop a method to analyze the dynamics of industrialization of advanced technology, suggests a framework for analyzing scenarios of industrialization of micromachine technology, and studies on such scenarios. Outline of the research is given below.

1. Introduction of micromachine technology to industry and society (technology-oriented survey)

First, we viewed and predicted current situations of R&D, applications that are already put into use, and future trend of elemental micromachine technologies, and contemplated, from a seeds-oriented viewpoint, in what form (of products and services) will micromachine technology serve future industrial society.

For analysis of the current situations of technologies and long-term prospects, the future of the following technologies, which are major fundamental technologies or elemental technologies of micromachine technology, are predicted based on the trends of current R&D.

(1) Processing and assembly technology: Classified in 17 technical items and surveyed.
(2) Device technology: Classified in 20 technical items and surveyed.
(3) System control technology: Classified in 12 technical items and surveyed.
(4) Fundamental support technologies: Classified in 10 technical items and surveyed.

A survey example is given in Table 1.

2. Demand in industries and society (demand-oriented survey)

Second, we considered contact points between the society and micromachine technology and needs for micromachine technology, and examined drive forces that accelerate industrialization, practical applications, and R&D of micromachine technology, as well as bottlenecks that may obstruct these motions.

We forecast changes in the environment to accept actual applications of technical innovation (micromachine technology) in the future, with a focus on the trend of various industrial and social cultures listed below, on which series of interactions with micromachine technology are expected to take place. Based on the results, we, viewed from the aspect of needs, predicted what would the society demand from micromachine technology.

(1) Changes in industry and economy: Changes in forms of manufacturing industry, changes in forms of machinery industry, high appreciation of the yen, dependency of industries on software
(2) Changes in society: Aging society with low ratio of birth, growing tendency toward environmental conservation, preparation of social infrastructure for the next generation
(3) Changes in living: Growing tendency of demand for security, growing tendency of demand for barrier-free living environment, permeation of life-long education
(4) Changes in technology: Progress of multimedia, progress of virtual reality, progress of biotechnology, progress of medical technology

3. Case analysis of technological innovation (industrialization process model)

We made case analysis on the process and impact of past technological innovations that occurred in various parts of the world, about by what process were the innovations industrialized and what impacts did they bring up upon from industry and economy to the society and people's living. We reviewed the cases to get a model of the process of industrialization of micromachine technology.

In the research, we studied and analyzed cases by the items below to find directions of change in recent R&D.

(1) Forms of enterprises shifting from manufacturing

Table 1. Survey data on processing and assembly technology (silicon process applied processing technology, surface micromachining)

Element technology item	Processing and assembly technology	Element technology detail	Silicon process applied processing technology
Name (level 1)	Surface micromachining	Name (level 2)	

Analytical item	Current situations	Future prospects
Outline of element technology (principle, structure, characteristics, etc.)	Principle: On a silicon wafer for semiconductor manufacturing, structures are formed by applying semiconductor manufacturing technology that forms layers of functional films and removes them selectively. Method: Functional films are formed mainly by physical vapor deposition (PVD) including evaporation and sputtering or chemical vapor deposition (CVD), and removed chemically by acidic or alkaline solution or radicals in low temperature plasma, or physically by ion milling. The process of formation and removal is repeated.	Method: Utilizing affinity with control and signal processing circuits, highly functional devices will be developed. New functions will be added by new functional film formation technology, improvement of film properties, and improvement of processing accuracy of removal.
Functionality and performance of element technologies	Geometrical processing: Practically two-dimensional processing with a processing depth of several micrometers Minimal processing dimensions: Dependent on photolithography Processing accuracy: Several micrometers by wet method, several atomic layers by dry method Applicable materials: Silicon, silicon compounds, metals, GaAs, InP, diamond film, piezoelectric materials, polymers Adaptability to mass production: High because of batch processing	Thick film formation technology and high-speed directional removal processing technology will be developed to be merged with bulk micromachining in terms of geometry forming. Later branches of the technology will be classified by the process affinity to the integrated circuit.
Applications of element technologies	Micro gyroscope, acceleration sensor, and other semiconductor sensors for measurement of physical quantities	Formation of various smart sensors by integration with the integrated circuit
Necessary preparation for R&D and application of element technologies	System configuration: PVD system (EB evaporator, RF sputter, ion beam sputter, etc.) Price: 5 to 30 million yen per unit System configuration: CVD system (low pressure CVD system, plasma CVD system, normal pressure CVD system, etc.) Price: 5 to 20 million yen per unit System configuration: Etching system (plasma etching system, wet etching system, etc.) Price: 1 to 20 million yen per unit Apart from equipment above, photolithography system, oxidation furnace, and other common semiconductor manufacturing facilities are necessary. If there is existing semiconductor manufacturing system, common use is possible.	System configuration: If development of monolithic devices with integrated circuits is aimed, use of semiconductor manufacturing facilities as they are is preferable. Price: Will vary linked to price variations of semiconductor manufacturing equipment.

Impact of application of element technologies put into use				
Images of final products	Medical field	Smart sensors for imbedded artificial organs (fail-safe and calibration functions implemented by circuit configuration)		
	Process field			
	Product field	High reliability smart sensors (self test implemented by circuit configuration)		
Other technologies to be merged to make high-impact technological innovation	Target technologies to be merged	Bulk micromachining, bonding technology, LIGA process, micro stereo lithography	Major reasons	Although surface micromachining is less advantageous for geometric reasons, development is ongoing because of easy starting by using semiconductor manufacturing system and great possibilities in making monolithic integrated circuits. In the future, three-dimensional processing technology compatible to integrated circuit process will be focused.
Time of use in practice	Partial utilization	1993	Major reasons	Intelligent acceleration sensors have already been put into the market. Development of a gyro having comb electrodes have also been reported on newspapers.
	Full utilization	2000	Major reasons	Since not the unit processing technologies but an entire complex system is expected in the future, various micromachine technologies must line up.
Others (remarks, references, etc.)	*"Micromachine, the Super Technology"* by the Micromachine Research Community, The University of Tokyo (NTT Publication, 1993)			
Related graphics				

to creation

(2) Business approaches changing from spin-off to trickle-up

(3) R&D to counter invisible enemy

(4) Product development based on demand articulation

4. Scenario of industrialization (micromachine industrialization process)

We tried to develop a method of dynamic analysis of the industrialization of advanced technology, and suggested the methodology for a framework to consider the scenarios for industrialization of micromachine technology. It was found especially important to check the five items below to predict the scenario of industrialization of micromachine technology.

(1) Introduction of micromachine technology (prospect of future technical seeds of micromachine technology)

(2) Demand of industry and society (prospect of future needs for micromachine technology)

(3) Driving force for industrialization (accelerating factors of industrialization)

(4) Bearer of micromachine industry (prospect of future micromachine industry)

(5) Impact upon industry and society (impact to be brought up by micromachine technology)

Selecting three fields, that is, medicine, process, and product, where application of micromachine technology on a test basis is expected, we used the method to consider specific scenarios of industrialization. Examples of industrialization scenarios in the medical field are shown in Table 2. From these scenarios, three keywords for the industrialization of micromachine technology were introduced. They are: low-invasive medical technology, microfactory, and autonomous and dispersed society.

In fiscal 1996, we are going to draw more detailed and specific scenarios of the industrialization process for micromachine technology using analytical methods.

Table 2. Scenarios for industrialization of micromachine technology in medical field

	Present	The year 2000	The year 2010
Introduction of micromachine technology in industry and society	·Low-invasive endoscopic surgical operation	·Anti-thrombogenic bio-compatible materials (for short-term use) ·Painless injection ·Cell injection (gene therapy) ·Sustainable drug administration ·DDS ·Imbedded organs	·Anti-thrombogenic bio-compatible materials (for long-term use) ·Sustainable drug administration ·DDS ·Imbedded organs
Demand in industry and society	·Rise of national medical costs (over 20 trillion yen in 1990) → Increasing necessity for low-invasive treatment method		
Impact upon industrial and social structures	·Drastic reduction of burdens on patients ·Drastic reduction of side effects of drug treatment ·Drastic reduction of hospitalization period	·Growth of medical equipment industry in market size and technology ·Use of DDS in practice → Formation of new industry on the border between pharmaceutical industry and medical equipment industry ·Changes in role of medical staf	·Suppression of rise of national medical costs ·Fulfillment of education system on use of medical equipment ·Entrance of qualified micromachine operators
Bearer of micromachine industry	·Existing industries ·Pharmaceutical industry ·Medical equipment industry	·Formation of new industry on the border between pharmaceutical industry and medical equipment industry ·Action on the part of industry is required to deal with administrative control on pharmaceuticals, administrative approvals, PL law, and so on.	
Driving force to industrialization		·Support of R&D for practical applications ·System construction in the industry for acquisition of safety and reliability	

Summary of Report on "Study for the Application of Micromachine Technology"

We conducted this survey for utilizing micromachine technology in new fields of application commissioned by the International Robotics and Factory Automation Center, which in turn was commissioned arrangement of the survey by The Mechanical Social Systems Foundation.

In this project we surveyed:
(1) prospects of new micromachine technologies that may emerge from interactions with biomimetics and biomechanics where excellent features of living organisms are studied by mechanical and material-scientific approaches, and, (2) feasibility of utilizing of micromachine technology in new prospective fields of application such as the earth environment management, agriculture, and urban life, beyond the limits of the medical and industrial fields that have been assumed as major application fields.

We set up a committee and a working group for this survey: Senior Researcher Tokio Kitahara at the Mechanical Engineering Laboratory of the Agency of Industrial Science and Technology presided over the committee, and Associate Professor Takashi Kiriyama at Research into Artifacts, Center for Engineering (RACE), The University of Tokyo, led the working group. We hired an expert research agency to survey on trend of technology in foreign countries, in parallel we held a workshop abroad to survey trends and needs of micromachine technology overseas, and the results were made into the report.

The survey results are outlined below.

1. Micromachine technology and biology

Current situations of research on biofunctional molecules, biomechanical molecules, microorganisms, and insects were surveyed, functionality of living organisms were examined, and the feasibility of application of such functionality was estimated.

Biofunctional molecules have been in use as medical materials exploiting membrane functions for blood dialyzing membrane, artificial skin, and drug release control membrane. As living organisms they have been utilized as enzymes for fermentation. Immunity mechanism has also been researched and developed into practical applications like the immune sensor and enzyme sensor. Another new attempt is research and development of a nerve interface by applying bio-computers and micromachine technology.

As for biomechanical molecules, we surveyed situations of study on flagellum motors and the mechanism and structure of muscle as actuators. Researches are ongoing on systems of insects as micromechanisms, such as motion characteristics, task sharing in a group, coordinated activity, and information transmission.

The conclusion of the survey is that new forms of micromachine technology may be conceived and modeled on such organisms, or new micromachine tools and systems necessary to accomplish these studies may be created in the future, that we have to continue to pay attention to these fields.

2. Micromachine technology and earth environmental management

Current situations of earth environmental issues, problems, and trends in research and development have been surveyed. Among the earth environment issues are ozone holes, global warming, acid rain, air pollution, water pollution, ocean pollution, recession of tropical rain forest, desertification, and (recycling of) waste, all of which are increasingly serious and researches and developments are conducted for countermeasures.

The most probable contribution of micromachine technology to solve earth environmental issues would be sensors for monitoring the environment or sensors for analyzing environmental load factors. If sensors are to be loaded onto an artificial satellite to monitor earth environment from outer space, the nature of micromachines, compactness and lightness, will be essential.

3. Micromachine technology and agriculture

Current situations of agriculture in Japan and Europe were surveyed and possible needs for micromachines considered.

The core of Japanese agriculture is the irrigated rice field, which is characterized by a tolerance to repeated cultivation of the same crop, readiness for the use of machines, and heavy dependency on water control. Problems in agriculture in Japan are poorly machine-facilitated vegetable growth, extremely low level of self sufficiency in food, and minor scale of individual agriculture operations mainly supported by persons having a side job.

On the other hand, in Europe, the three-field system prevails, where repeated cultivation of the same crop on the same ground is impossible and stock raising yields the most important part of the produce while fertilizing the land, as well. Apparently automation of agriculture is not brisk, nor is the agricultural machinery industry.

Current needs in agriculture possibly related to micromachines are: information management technology for cultivation data such as soil conditions, degree of ripeness, and quality judgment; highly automated robotic operation technology and automated operation technology; automation and labor operation technology for toil-free, safe work environments; and improvement utilizing biotechnology.

Other application ideas being conceived are: fruit quality measurement, detection of root taking or scion fixation by measurement of culture electroconductivity using laser sensors, plant status monitoring that directly checks sap, cell quality check and direct operation of cells with micromachines, and analysis of bruise of fruits and measurement of picking force using micro force sensors and automatic fruit picker robots.

Application ideas to stock raising are: sensors for detecting sexual excitement or breast inflammation of cows, monitoring of physical conditions (from inside or outside the body), monitoring of body temperature, pH, blood-sugar level, and so on.

4. Micromachine technology and urban life

Possible relations between micromachines and urban life have been sought for.

In urban life, where utilization of information will be accelerated, micromachines may be used at the point of interface between information networks and people. Possible applications of micromachines to the living environment, health, business, security, and entertainment, which are predicted to increase significance in future urban life, have also been surveyed.

There are possible micromachine applications to urban life such as high functionality living environment and buildings using micromachines, health equipment, security systems, entertainment equipment, and means of artistic expressions.

5. Operation of workshop overseas

We held a workshop in the Netherlands where brisk activities are taking place to research and survey application of micromachine related technologies to agriculture, stock raising, and gardening.

At the University of Twente, members of our research working group joined with experts in agriculture or micro system technologies (MST) from five European countries (the Netherlands, Germany, the U.K., Switzerland, and Belgium) and discussed applications of micromachines to agriculture.

It seemed that in Europe they have vigorously put micromachines, especially sensors to practical use.

6. Collection and analysis of overseas technology information

Information about trends in the development of micromachine technologies and trends of governmental support in Europe and the U.S. was collected and analyzed.

(1) Situations in Europe

The policy of the Germany Federal Government in budget planning is to prioritize education, research and development, and technical ability development. As such, the research and development subsidy has been raised by 2.3% over last year to 15.6 billion marks. Biotechnology, environmental technology, and information and communications technology are allocated with the most generous subsidiaries. To micro system technologies, 106 million mark is budgeted.

As the budget tells us, MST weighs much in R&D promotion policy of the German Research and Technology Ministry. In 1994, a total of 153 projects were ongoing, including R&D aiming to create unique and original products such as micro sensors, micro actuators, signal processors, and micro systems.

The trend of R&D is toward concentration of resources upon MST basic technologies such as silicon micromachining, LIGA process, hybrid systematization technology, packaging, energy sources, photothermal and photoelectric converters. Major application fields of MST aimed are instrumentation, medicine, consumer products, and agriculture.

In Europe, the Network of Excellence in Multifunctional Microsystems (NEXUS) is working actively. NEXUS, sponsored by EU, coordinates the micro system market and R&D organizations in the entire Europe. To clarify industrial needs and strategies, the Industrial Working Group (IWG) was organized and has started to work to plan strategies to permeate through the market, put new products on the market, and predict market scale.

(2) Situations in the U.S.

What we Japanese call as micromachine technology is referred to as Micro Electro Mechanical Systems (MEMS) in the U.S.

In the U.S., MEMS is mainly studied at colleges and universities and federal research institutes. While sensors are the most important application of MEMS technology, displays are also hopeful. Because of the expected low cost and compactness, a wide range of application fields are conceived from automobile airbags and air brakes to flow monitors.

From October 29 to November 3, 1995, the Micro Nanotechnology International Conference was held at Houston, Texas to discuss application to the space science. At the event it was explained that micromachines, as having the essential nature of compactness and lightness, were expected to be applied to space science in the forms such as sensors, actuators, and energy sources. Examples of micromachine-applied mechanical gyros, accelerometers, and cases of system development of such equipment were also reported.

7. Conclusion

In searching for new applications for micromachines, problems in earth environmental management, agriculture, and urban life have been picked up and analyzed. In the future it will be necessary to further clarify possible applications of micromachine technology, as well as to examine their technical feasibility.

Summary of Report on "Study for the Standardization of Micromachine Technology"

1. Introduction

Micromachine technology is a wide interdisciplinary field covering numerous areas of science and technology, including mechanical engineering, electronics, electrical engineering, and medical engineering, and embracing the basic sciences such as physics, chemistry and biology. Because micromachine technology embraces various disparate fields, micromachine researchers must establish common ground and consensus for technological interchange within the same field or between different fields. Efforts must be made to standardize the concepts of micromachine technology to enhance understanding.

But micromachine research is still at a relatively early stage, and promoting excessive standardization prematurely could stifle its progress. The case for micromachine standardization is different to the case for standardization within mature technologies. Micromachine standardization must be pursued hand in hand with micromachine technology, but if occasion demands, the former could precede the latter. Standardization that will encourage rather than suppress the development of this growing area is essential. The micromachine standardization project is being promoted by the Standardization Committee to systematically establish micromachine technology and spread it to various fields.

2. The Organization of the Standardization Committee and its Project

The Standardization Committee is composed of professors, representatives of the Standards Department of the Agency of Industrial Science and Technology (AIST), the divisional directors of three national research institutes of AIST, and representatives of MMC' s research supporting members. The Committee is mainly concerned with examining the following areas: (1) long-term policy of the Standardization Project, (2) international standardization, and (3) the project commissioned by The Japan Machinery Federation.

2.1 Long-term policy on the Standardization Project

In fiscal 1993, the Standardization Committee examined the aspects of micromachine technology to be standardized. These were identified as (1) definition of terms and concepts, (2) measuring and evaluation methods, (3) elements (form and performance), and (4) technology applications. By the end of fiscal 1995, the Standardization Committee had completed an investigation of the definitions of terms and of measuring and evaluation methods.

2.2 Study of international standardization

Standardization of micromachine technology is being advanced through close coordination with overseas institutions. In fiscal 1995, the IEC (International Electrotechnical Commission) identified four micromachine-related fields requiring standardization in the near future, and a project team was formed to promote standardization. Representing Japan, the MMC is cooperating with the IEC in this standardization. The project team created an exhaustive questionnaire on topics relating to micromachines. This questionnaire covered the scope and range of micromachine technology to be standardized, market research, production and packaging, and such technical areas as interfaces and control systems. Members of the Standardization Committee responded to the questionnaire, and Mr. Takeo Sato of Matsushita Research Institute Tokyo, Inc. was assigned to the project team meeting. The IEC secretariat is working to establish TC.

3. Project Commissioned by The Japan Machinery Federation

The MMC, which was commissioned to undertake the project for the standardization of micromachine technology by The Japan Machinery Federation, established a standardization investigation subcommittee under the main Standardization Committee to frame a plan for advancing the project. Under the guidance of the subcommittee, the MMC established a working group on micromachine technology-related technical terms and another group on measurement and evaluation methods for micromachine technology.

3.1 Activities and results of the working group on technical terms

In any framework for the standardization of micromachine technology, the standardization of technical terms forms a central plank. To avoid misunderstandings and confusion among different technological fields, it is necessary to study, identify, and clarify the meanings of technical terms and to obtain basic data to create uniform definitions. In addition, defining technical terms simply and clearly facilitates entry to the field of micromachines and is useful in promoting education on micromachines. In the future, the results of the study will be utilized to create standard technical terms or be used to draft JIS (Japanese Industrial Standards) or ISO standards.

By the end of fiscal 1994, the working group had collected and analyzed many terms relevant to micromachine technology and had defined the terms deemed particularly important (183 terms). In fiscal 1995, the terms were systematized in accordance with their relevance to micromachine technology and their category (e.g., element or application). Each term was also classified into one of three further categories (e.g., as general term, as the name of a specific instrument) and its relationship to other terms was clarified. As a result, 40 technical terms relating to general concepts were added to the terms collected in fiscal 1994. This list was shown to other MMC staff and reviewed and revised in accordance with their feedback. As a result, three terms were deleted and the meanings of 220 technical terms were examined.

3.2 Activities and results of the working group on measurement and evaluation

This group will collect and analyze literature on measuring methods applicable to conditions affecting micromachine technology. The methods will be evaluated in light of their comparative advantages and disadvantages and the technical problems to be solved. Thus, the group will collect basic data for standardizing measurement and evaluation (or will clarify technical problems that must be solved for standardization to take place).

In fiscal 1993, the working group examined the measurement and evaluation needs of national research institutes and MMC' s research supporting members, and identified high-priority areas for standardization.

Throughout fiscal 1994 and 1995, the group researched the progress already made into standardization in these priority areas through various literature. Currently, it is still collecting material on the main methods and categories of measurement, and has prepared a data sheet clarifying the outlines of its research. Although the data sheet is very similar to that produced in fiscal 1995, the revised sheet identifies which literature refers to which measurement methods, making it easier to access data.

(1) Measuring forms and dimensions

A sub-working group studying measurement and evaluation of forms and dimensions retrieved information on micromachine patent rights through PATOLIS (Patent On-Line Information System). Since 1972, 1171 micromachine-related patents have been made public, of which 536 were released after 1990 and 382 subsequent to 1992. Applications for micromachine patent rights have clearly been increasing in recent years.

As objects to be measured are becoming smaller and finer, it is becoming necessary to study how to fix and handle objects and how to specify places to be measured, and also to develop support systems for staff involved in measuring.

(2) Measuring force and torque

Force and torque measurement requires the development of on-chip test-pieces or experiment apparatuses, such as a force sensors with impurity-doped diffusion-type strain gauges on a silicon base. In addition, mounting processing circuits on chips helps standardize evaluation internationally. While the possibility of other quantitative measuring methods has not yet been studied, a measurement of other quantity has been achieved with an acceleration sensor already in use. To standardize measurement of force and torque, methods must be found that can be easily standardized internationally. Truly valuable standardization methods will be established only through the active exchange of information among researchers.

(3) Measuring fluids

In measuring fluids, the MMC is focusing on flow rate and pressure. Various methods are being tested for measuring liquid flows in the wide range of 1 μl/min to 1 l/min, the range considered necessary for the calibration of micropumps. However, measurement of gas flows under 1 ml/min seems to be difficult. To measure pressure over 1000 Pa (1/100 atm) a microsensor based on semiconductor technology has already been developed and deployed, and a micromanometer is being developed for measuring pressure below 1000 Pa. The MMC has researched the measuring units used in the scientific literature. SI (m/s) is mostly used as the unit of flow velocity, and volume per minute (ml/min) is widely used as the unit of flow rate. For pressure, in addition to SI (Pa), various units (atm, mmHg, mmH_2O, gf/cm^2, psi, bar) are used. Usage appears to depend on the application field and the method of measurement, and this must be reassessed for standardization to be reached.

(4) Characteristics of materials

From fiscal 1995, the MMC began investigating the measurement and evaluation of the characteristics of materials. Based on use, materials can be classified into structural materials and functional materials. In fiscal 1995, by studying relevant literature, the MMC created a data sheet on evaluating the tensile and bending characteristics of structural materials, and on evaluating the piezoelectric characteristics of shape memory alloys and other functional materials.

Summary of Report on "Investigation on the R&D Trends of Micromachine Technology at Home and Abroad"

In fiscal 1995, the Subcommittee for the Investigation of R&D Trends of Micromachine Technology at Home and Abroad was established. Professor Koji Ikuta, Faculty of Engineering, Nagoya University was appointed chairman and a report was prepared of the subcommittee' s investigations. From its inauguration, the subcommittee began investigating and analyzing important micromachine technologies based on domestic and overseas literature. The following is an outline of the results of that investigation.

1. Processing technology

(1) Photofabrication technology
- A three-dimensional microstructure was produced by a combination of micromachine technologies.

(2) Non-photofabrication technology
- In the field of micromachine processing, combining non-photofabrication with photofabrication is an increasing challenge.

2. Microhandling technology

- Microhandling technology has become useful not only for operations using optical microscopes but also for those based on electron microscopes and AFMs (atomic force microscopes). Microhandling has now reached the order of nanometers.

3. Systematization technology

- Research into developing operation systems supported by micromachines and a control system for micromachines is increasingly essential.

4. Micro-science and engineering

- Numbers of microtribology research projects using SPMs (scanning probe microscopes) are increasing.
- The importance of micro-science and engineering is widely recognized. Micro-science and engineering has been developed as a practical system.

5. Microdevice technology

- Actuator driving systems have been improved in function and performance through the development of processing and molding technology.
- Research into sensors to detect mechanical parameters has expanded into the area of gas sensors and bio sensors, which appear suitable for micro-technologies.

6. Energy and information transfer technology

- Research into energy and information transfer technologies where application needs are clear is achieving steady results.

7. Industrial applications

- Micromachine technology is at the stage of researching and developing element technology, and results have already been utilized in mechatronics products and components.

8. Medical applications

(1) Artificial organs and instrumentation
- In instrumentation, microfabrication technology, including the development of sensors, has cleared the first stage of development. Research trends are moving from microminiaturization of devices to the long-term stable support of devices in a living body.

(2) Medical technology applications
- Micromachine applications in the medical field include an active endoscope/catheter, a self-locomotive endoscope, and a range of sophisticated instruments for surgical operations based on endoscopes. These are being vigorously and successfully researched.
- Recently, strides have been made in medical applications of virtual reality and micromachine technology as a result of combining these two technologies.

R&D Trends of Micromachine Technologies Investigated

Main areas	Secondary areas	Areas investigated
Processing technology	Photofabrication	Bulk micromachining, surface micromachining, LIGA processing
	Non-photofabrication	Mechanical processing, grinding technology, processing technology based on SPMs, ultrasonic processing, photoforming technology, processing and assembling technology, reactive ion beam processing
Assembly technology	Microhandling technology	Micromanipulation, ultra-micro operations, simplified micromanipulation, ultra-micro operation base
Functional element technology	Microdevice technology	Actuators: Electrostatic actuators, piezoelectric actuators, electromagnetic actuators, photodevices, switch/relay fluid devices, generating devices, etc. Sensors: Acceleration sensors, force sensors, pressure sensors, angular velocity sensors, electromagnetic sensors, visual sensors, tactile sensors, gas and fluid sensors, biosensors, etc.
	Energy and information transfer technology	Energy transmission technology: Cable energy supply, non-contact energy supply, energy storage, energy conversion Information transfer technology:
System control technology	Systematization technology	Operation system, control system
Fundamental technology	Micro-science and engineering	Tribology, fluid engineering, mechanics of materials
Application technology	Industrial applications	Sensors, functional parts, system integration
	Medical applications	Artificial organs: Nerve regenerating electrodes, nervous system multi-channel microelectrode arrays, artificial retinas, artificial inner ears, artificial muscle elements Instrumentation: Medical technology: Endoscope/catheter, medical instruments, others

Sapporo Micromachine Seminar

The Sapporo Micromachine Seminar was held on the afternoon of Thursday, September 5 in Sapporo by the Micromachine Center (MMC) jointly sponsored by the Hokkaido Bureau of International Trade and Industry (Ministry of International Trade and Industry), the Hokkaido Prefectural Government, the Hokkaido Technology Advancement Center, and the Hokkaido Foundation for the Promotion of Scientific and Industrial Technology.

Lectures were given in Training Room 820 in "Kaderu 2.7" of the Hokkaido Municipal Activity Center. Mr. Katsuya Makiuchi (Deputy Director, Industrial Machinery Division, Machinery and Information Industries Bureau of the Ministry of International Trade and Industry), Mr. Takayuki Hirano (Executive Director, MMC), and Dr. Tokio Kitahara (Senior Researcher, Mechanical Engineering Laboratory of MITI' s AIST), delivered lectures respectively on "The New Policy of the Ministry of International Trade and Industry in Fiscal 1997," "The Activities of the Micromachine Center," and "An Outline of Micromachine Technology."

"The New Policy of the Ministry of International Trade and Industry in Fiscal 1997," in particular, revealed the measures for fiscal 1997 to be taken by the Industrial Machinery Division of the Machinery and Information Industries Bureau of the Ministry of International Trade and Industry. These included innovative research and development into new production technologies, the creation of new industries, and research aimed at promoting a cyclical-type industrial society. The main points of MITI' s Industrial Machinery Division policy as revealed in the lecture are:

1. Innovative research and development into new production technologies

Manufacturing industries in developed countries face such problems as the globalization of corporate activities, a shortage of skilled workers, and the reluctance of young engineers to enter the manufacturing industry. The following R&D projects will attempt to solve these problems: 1) systematization of joint research by Japan, the United States, Europe, Canada, and Australia into realizing next-generation manufacturing technology that highly integrates overall production processes; 2) large-scale development of micronization for the development of micromachines that can perform microscopic and complex operations; 3) large-scale development of advanced instrumentation and processing technologies to build an innovative measuring and processing technology system using photons with good controllability as tools, and to establish micro to macro processing technologies.

2. Creation of new industries

This leading research project seeks to develop remote-controlled robot technology with the aim of building a mechanical system composed of intelligent robots joined in a network by combining machine technology, information technology, and communication technology. The project also seeks to build an information system industry that integrates machine and information network technologies. The project seeks to realize mechanical standards for the preparation of an environment to promote unification and to publicize interface and other specifications.

3. Survey and research to realize a cyclical-type industrial society

Research into the development of a next-generation recycling system to realize "machinery that does not mechanically degrade." The project uses design and module technologies that reflect the total product cycle, and researches maintenance technologies on the collection of technologies, data, and joint ownership of information required to prevent functional deterioration caused by obsolescence and to maintain functions such as convenience and safety in the social capital.

In addition, the following lectures introduced the results of the Industrial Science and Technology Frontier Program "Micromachine Technology."

"Research into microscanners and piezoelectric thin film actuators"
Minoru Sakata (Central R&D Laboratory, Corporate Research and Development H.Q., Omron Corporation)

"Microlaser Catheters"
Shigeru Omori (Research and Development Center, Terumo Corporation)

"Microantenna-Type Infrared Spectrometers"
Hideaki Yamagishi (Central Research Laboratory, Yokogawa Electric Corporation)

"Electromagnetic and Electrostatic Microactuators"
Satoshi Sugiura (Functional Device Laboratory, Fuji Electric Corporate Research and Development, Ltd.)

The seminar was attended by about 70 people engaged in R&D and production of micromachines at companies, universities and research institutes in Hokkaido.

Seminar in Sapporo

Japan Robot Association

1. Introduction

A visit was made to the Japan Robot Association (JARA). JARA's ancestor, the Industrial Robot Conversazione was established in March 1971 as a voluntary organization dedicated to the "sound development and prosperity of the industrial robot industry". The organization promoted industrial robots, and in 1972 changed its name to the "Japan Industrial Robot Association". In October 1973, it was reorganized as an incorporated body, the "Japan Industrial Robot Association" for the purpose of actively advancing its activities and clarifying its rights and duties.

In June 1994, the Japan Industrial Robot Association was again reorganized and expanded into the "Japan Robot Association" (also an incorporated body). This change was made to establish a system to promote and develop non-industrial robots such as the robots for social welfare purpose including the daily and work support for the elderly and the disabled, and the personal robots for home use and leisure, as well as the industrial robots that have been the major object of promotion by the JARA.

2. Main activities

The Association comprises seven standing committees and a Personal Robot Council, whose role is to carry out activities supporting the development of robots and applied systems. The following describes the principal activities of the standing committees and council.

The Policy Committee deliberates on policies for the promotion of robots and technology development, on ideas for governmental assistance programs and other national policies, and on plans for implementation of the association activities.

The Public Relations Committee publishes bulletins, reports and other periodicals, and edits and publishes "The Robot Handbook", "Specifications and Applications of Robots in Japan", "Collection of Catalogs" and other publications. It also organizes international robot exhibitions, training courses on application of robots and technology, symposiums, video festivals, and factory technical visits, etc.

The Marketing Committee, aiming for implementation of activities for the promotion of smooth and healthy growth in robot, tabulates statistics on order bookings, production volumes and shipment volumes, and estimates long-term demand (for the manufacturing and non-manufacturing fields). To encourage sales, it also supports interest-free loans, government loans, and tax incentives. This committee registers engineering companies to promote the development of the engineering industry and develops measures for the promotion of the various types of robot (including welding, painting, assembly and PCB assembly robot).

The Technology Committee conducts technology research such as the long-term technology forecasts, the survey of trends of research institutes and organizations, and the survey on patent. Its activities also include making draft proposals for Japan Industrial Standards (JIS), making association standards for industrial robots (JARAS), and working on International Standards (ISO) and other standardization.

The Safety and Automation Models Committee plans for new fields in both the manufacturing and non-manufacturing sectors from the standpoints of guaranteeing workers' safety and providing more humane working environment, and promotes the development of robot systems for application in these fields.

The Systems Committee promotes cooperation with MITI's "Micromachine Technology" of Industrial Science and Technology Frontier Program, which is being promoted as a large project, researches and develops robots and applied systems, and promotes the development of new application technology and the expansion of application fields.

The Overseas Committee takes charge of implementation of international industrial cooperation and technology exchanges. It organizes various international conferences in Japan, such as the International Symposium on Industrial Robots, the International Conference on Advanced Robotics, the International Symposium on Automation and Robotics in Construction, and the Asian Conference on Robotics and Its Application. To promote effective technical exchanges, it sends survey missions to conferences and symposiums held abroad while it hosts overseas study groups. It also administers the JARA Awards and translates and publishes foreign literature.

The Personal Robot Council carries out formulation of basic policies, promoting R&D policies and diffusion policies, for the purpose of promoting the R&D and diffusion of personal robots.

The Association is endeavoring to develop plans for the promotion of R&D of advanced robots including micromachines, to standardize robots, and to pursue such activities as publicity promoting the popularization of robots and international technical exchanges. With the active commitment of the Association, future advancement in the robot industry is assured.

Japan Power Engineering and Inspection Corporation

1. Introduction

Japan Power Engineering and Inspection Corporation (JAPEIC) is a statutory foundation established in 1970 as a third party inspector to inspect, test, and research on power plants for the purpose of enhancing their facilities quality. Since its establishment, JAPEIC has mainly conducted welding inspection on thermal and nuclear power plant in accordance with the Electric Utility Industry Law. JAPEIC began to conduct some other inspections for nuclear power plants in 1980 and was authorized as a designated inspection organization in 1984 under the Law, and has conducted pre-service inspection and periodical inspection in addition to welding inspection.

Thermal and nuclear power plants must be subjected to welding inspection, in case of being welding of designated components, and pre-service inspection under the Law. Unless the facilities pass these inspections, they can not operate.

In thermal power plants, boilers and steam and gas turbines with a capacity of 1000 kW or over must be required periodical inspections, and then, JAPEIC conducts some of these inspections as an authorized inspection agency of the Ministry of International Trade and Industry (MITI).

Nuclear power plants are also subject to periodical inspection under the Law. Reactor facilities must be inspected annually, and turbine facilities every two years. JAPEIC has been charged with these periodical inspection conducted by the power suppliers themselves.

To improve the quality of the inspection, JAPEIC actively researches and tests on the safety and reliability of thermal and nuclear power plants and inspection and welding technology, further more, is engaged in commissioned researches and other engineering services.

2. Details of research and development

JAPEIC is engaged in researches, technical development and verification tests, as commissioned and subsidized by MITI or its own fund, aided by the research and development Center (consisting of the Coordination Department, the Tokyo R/D Center, the Tsurumi R/D Center, and the Tarasaki R/D Center). These activities are inspection technology, welding technology, quality assurance, maintenance, integrity and aging of thermal and nuclear power plants and etc.

The Tokyo R/D Center plays a central role in the research and development activities, commissioned by MITI, improving the reliability and analyzing and verifying the integrity of power generating facilities. The Tsurumi and Tarasaki R/D Centers promote the inspections and tests, with their own equipment on, improvement of non-destructive inspection and other inspection technology, as well as welding technology.

3. Micromachine Research

Micromachine technology has great potential and much capabilities in the application field and is expected its development. On the other hand, micromachine technology ranges over broad fields and are required various technologies and their development. Therefore, to establish technologies for the early realization of micromachine systems, it is necessary to clarify the direction of micromachine R&D and promote R&D efficiently and effectively.

JAPEIC is engaged in study on the future application of micromachine technology to the maintenance of power plants, and clarifies the concept of maintenance micromachine systems based on the needs of plant operators. JAPEIC is making effort to present so appropriate targets for micromachine R&D that micromachines, in future, have a effective role to play in power plant maintenance.

Test piece

Test equipment

Verifying test on the integrity of plant equipment

Micromachine Seminars in Europe

Micromachine lecture meetings were held in Spain and Switzerland as part of the BPG activities conducted by the Japan External Trade Organization (JETRO) to promote international exchange of micromachine technology between Japan and Europe. The following are the details of the events.

"MICROSISTEMS I MICROMAQUINS"
Date: September 13, Friday, 1996
Place: Universitat Politecnica de Catalunya, Barcelona, Spain
Topics and Lecturers:
"Activitats GAME en Microsistems"
Luis Castaner, Universitat Politecnica de Catalunya
"Procesos y Celdas para Microsistemas"
Emilio Lora, CNW
"Micromachine Activities in Southampton"
Graham Ensell, Southampton University
"Future Prospects of Micromachines"
Takayuki Hirano, Executive Director, Micromachine Center
"Current Status of Micromachine Technologies in Japan"
Tadashi Hattori, General Manager, Research Laboratories, Denso Corp.
"The Progress of Microfactory Technology"
Toshihiko Sakuhara, General Manager, Microsystem Dept., Corporate R&D, Seiko Instruments Inc.

"Seminar on Micromachines in Japanese Industry"
Date: September 20, Friday, 1996
Place: Beaulac Hotel, Neuchâtel, Switzerland
Topics and Lecturers:
"Programme Minast, Micro & Nano Systems"
Nico de Rooij, University of Neuchâtel
The Japanese lecturers and their subjects are the same as for the lecture meeting in Spain.
MMC's activities were introduced by video.

Forty participants, including many students, made the seminar in Spain a great success and engaged in lively exchanges of opinion.

The seminar in Switzerland attracted 60, more than initially expected, demonstrating the interest micromachines attract in Switzerland. While appetizers were being served after the seminar, one of the Swiss organizers remarked excitedly: *"The participants are all talking about the seminar. It must have been a great success!"*

Because of the popularity of such seminars, still higher and more frequent levels of technical exchange can be expected in the future.

MST '96 Held in Potsdam

Located to the west of Berlin, Potsdam is a small and quiet city with a population of 140,000. MST '96 (MICRO SYSTEM Technologies 96) was held at the Residence Hotel in the suburbs of Potsdam from September 17 through 19. The area is surrounded by woods, and a complex of apartments and supermarkets has been built about five minutes' walking distance from the hotel. The seminar attracted approximately 390 people, including 17 Japanese. Although the participants' book did not record nationalities, many participants were from Germany, and some from neighboring Switzerland, France, Italy, and other European countries. Lectures were held in a large conference room with seats arranged in tiers, and in small rooms (The rooms were too small in some case to accommodate the large audience.) in a three-story building contiguous to the hotel. The exhibition hall was enlivened with displays from about 30 companies.

Lectures by their content are shown on the list (tutorials are not listed). On the first day, the opening plenary talks were held. Takayuki Hirano, Executive Director of the MMC received a very enthusiastic response to his speech about Japanese activities of micromachines and their future prospects. A speaker from the United States talked about the history of silicon semiconductors and their packaging. Another American reported in the Plenary Session that MEMS (Micro Electro Mechanical Systems) were attracting interest and investment in government circles. The total market for MEMS sensors was $145 billion in 1995, expected to quadruple by 2005. Nippondenso Co., Ltd. enjoyed an enthusiastic response to the presentation of some results from the "Micromachine Technology" of R&D project in Industrial Science and Technology Frontier Program. Many of the speakers were from the Fraunhofer Institute, the Technical University of Berlin, and the University of Bremen. A large proportion of the presentations were joint projects by research institute and university, company and university, between universities in the same country, or between universities in the countries surrounding Germany. Quite clearly, Europe, and Germany in particular, is enthusiastic about micromachine technology, and exchanges in the region are frequent.

The first day's banquet was held in a large restaurant of the Residence Hotel, and on the second day in Cecilienhof Palace where the Potsdam Declaration was drafted. Lively discussions continued until midnight.

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Presentation of Micromachine Technology Research Results Supported By the Second Research Grant

The research grant system began in 1993 as an independent activities of the Micromachine Center to support university staff engaged in basic research on micromachines. Objectives were to promote micromachine technology and encourage further exchange between the academic world and industry.

Three two-year research projects supported by fiscal 1993 grants and three one-year projects supported by fiscal 1994 grants were completed in March this year and reports have been prepared on the projects. An official Presentation of Results of Research Projects Supported by the Second Micromachine Technology Research Grant was held on Thursday, September 26, 1996 at the meeting room of the Micromachine Center. The latest information was presented using overhead and slide projectors (See the list below. Professor Kataoka was absent on an overseas business trip and therefore unable to present his results.). In particular, the results of research into micromachines, peripheral equipment, and future tasks were introduced clearly and effectively. The audience was very interested in the results of research projects into materials for micromachines and medical applications, which formed the focus of the presentations, and lively questions and answers were exchanged. The presentations were a great success.

The results of the six research projects are already outlined in "MICROMACHINE No.16."

Research Projects Supported by Micromachine Technology Research Grants

(Bold letters indicate reporters and subjects)

Leader and Co-Worker	Positions	Subjects	Period
Shuichi Miyazaki	**Associate Professor, Institute of Materials Science, University of Tsukuba**	**Basic Research on the Development of Shape Memory Alloy Thin Films for Microactuators**	2 years*
Eric Yeatman Richard Syms	Lecturer, Head of Section, Imperial College of Science, Technology and Medicine, University of London	Surface Tension Micromolding and Microactuation	2 years*
Kunihiko Mabuchi Iwao Fujimasa	**Associate Professor,** Professors, **Research Center for Advanced Science and Technology, The University of Tokyo**	**Basic Research on Application of Micromachine Technology in the Development of Remote-controlled Microsurgery Systems**	2 years*
Kazunori Kataoka	Professor, Faculty of Engineering Science, Science University of Tokyo	Development of Novel Techniques for the Creation of the Surface with Superior Biocompatibility	1 year**
Yasunori Saotome Akihisa Inoue	**Associate Professor, Faculty of Engineering, Gunma University** Professor, Institute of Materials Research, Tohoku University	**Microforming and Fabrication of Micromachines with Amorphous Alloys**	1 year**
Ken Suzuki	**Assistant, Institute of Biomedical Engineering, Tokyo Women's Medical College**	**The Stable Coating of Biocompatible Materials on Micromachine Surfaces**	1 year**

*: Research projects granted in fiscal 1993
**: Research projects granted in fiscal 1994

Application of Micromachine Technology (I)

In the previous series of articles on this page concluded preceding time, we have explained on fundamental technology, device technology, and system technology that compose micromachine technology as a whole. I think you may have noticed that micromachine technology is a general-purpose technologies that has a considerably wide scope of applications. In addition, an important characteristic of micromachine technology is that great effects are expected even from use of a single element technology such as micromachining technology or material technology. Needless to say, when all micromachine technologies are full-fledged to the level of practical application, micromachine systems as innovative application systems will be in use in much broader fields.

Figure 1 shows the major applications fields of micromachine technology in a tree diagram. The Micromachine Center is studying forms of actual applications in these fields, their expected effects, and problems in realization, as well as surveying the status of progress of technical development and social needs.

This introductory course starts a new series in this issue, in which we will take up examples of application fields where expectations for micromachine technology are high, and see what needs are there and what R&D will be necessary for implementation. The first example is the application to medical treatment, which is a close subject to us all.

1. Application to Medical Treatment

1.1 Introduction

Much is expected for application of micromachine technology in the medical field. Recently, less invasive diagnosis and treatment that harms the body less and gives the patient less pain is called for. The demand for medical micromachines (machines miniaturized by micromachine technology used for microscopic, intricate diagnosis and treatment) is on the increase. In surgical operations on internal organs for example, if micromachine technology can make medical diagnostic and treatment instruments that are by far smaller and more versatile than conventional ones, such instruments can be inserted easily into the body of a patient with no major surgeries like in an abdominal operation, and work directly on the diseased part. This drastically relieves patients' burdens including physical and mental pains and time and expenses of hospitalization. There are many other applications hoped for, as described in the following.

1.2 Expected Fields of Application of Micromachine Technology

(1) Facilitation of planting instruments under the skin by miniaturization and function integration
- Imbedded artificial organs and other imbedded bio functionality replacing organs, cells, and tissues (artificial organs and implanted tissues)
- Internal monitoring equipment that incorporates micro sensors
- Ear interior hearing aids

(2) Facilitation of access to diseased or diagnosed parts by miniaturization
- Drug delivery system with micro capsules
- Collection of sample cells for diagnosis

(3) Facilitation of advanced microscopic treatment
- Precision microsurgery of the brain, eyes, and nerve
- Tele-operation surgery, robot surgery, computer-aided surgery

(4) Facilitation of less invasive diagnosis and treatment by miniaturization and function improvement
- Celoscopic surgery (intracelomic surgical treatment) by inserting instruments through the skin without opening the abdomen or the chest and conducting a surgical operation in the abdominal or thoracic cavity, less invasive remote microsurgery
- Intraluminal procedure (intraluminal diagnosis and treatment) by inserting fine tubes into the body to diagnose with sensors or treat a clogging or bossed blood vessel or alimentary tract from the inside.
- Low invasive examination, micro probe inspection and internal in-situ test

Such applications are expected almost all parts of the human body from brain and nerve to organs and the inside of tissues, as well as lumens such as blood vessels, alimentary tracts, air tubes, and urinary organs, and body cavities typically the thoracic cavity and abdominal cavity. Size reduction of instruments provides us the opportunity of inspecting the body internal parts without causing damage to the body, which has been impossible. It also makes highly accurate and efficient diagnosis and treatment possible.

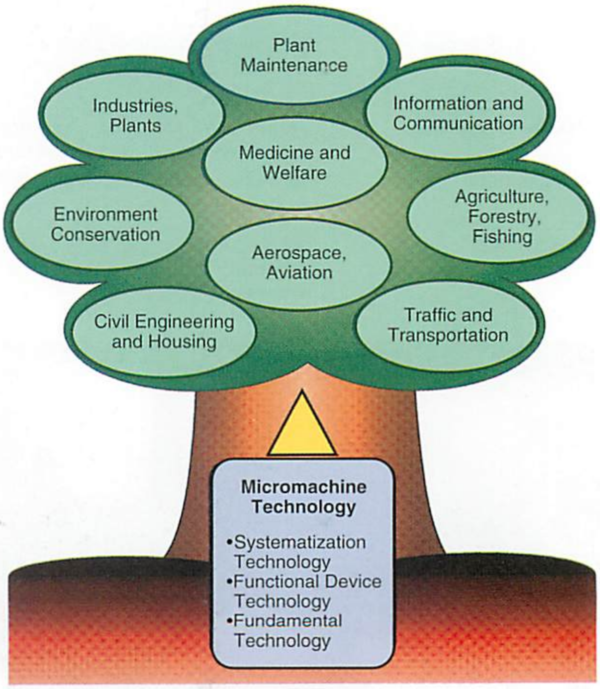

Fig. 1 Fields of application of micromachine technology

Table 1 Necessary R&D

Function	Necessary R&D
Sensing	Micro tactile/pressure sensors, micro blood pressure and flow sensors, various blood analysis sensors, various bio sensors, space coordinate recognition sensors
Observation	CCD micro camera device, micro fiber scope, ultrasonic diagnostic device
Treatment	High accuracy micro manipulator, micro robot hand, micro actuator, remote controlled virtual reality, teleoperation technology, control technology
Drug delivery	Micro injection and infusion equipment, micro blood sampling equipment, micro pump, micro valve, capsule type drug delivery system
Electrical stimuli	Nerve interface, artificial retina
Systematization	High density mounting technology, systematization technology

Figure 2 shows a conceptual diagram of a body cavity internal diagnosis and treatment system that uses micromachine technology. Entering from a small hole in the skin, the machine goes into and starts treatment at the very core of the disease, such as in the depths of the brain that used to be inaccessible. By remote control of catheters inserted in the body, surgeons can treat the tip of an entirely clogged coronary artery or treat a cerebral aneurysm, a major cause of subarachnoid hemorrhage, while monitoring ongoing operations.

1.3 Necessary R&Ds

To make practical diagnosis and treatment micromachines described above, research and development must be conducted in a significantly wide range of fields listed in Table 1.

The R&D on the above medical micromachine technologies, needless to say, careful considerations must be given to materials, bio environment, safety, and reliability. Furthermore, R&D for medical validity and medical application must be conducted bearing closely on the field of bedside medicine, as well as technology to select safe materials for the organic body and various sterilization methods need to be developed.

1.4 Effects of Application

Micromachine technology is predicted to have an economic effect (predicted market scale) of 560 billion yen in the medical field of Japan only in 2010, which is the reason of high expectations in the technology in industries. It is not the mere economic effect that advancement of micromachine technology in the medical field will provide us: it will make our society more affluent with medical and welfare equipment caring to people.

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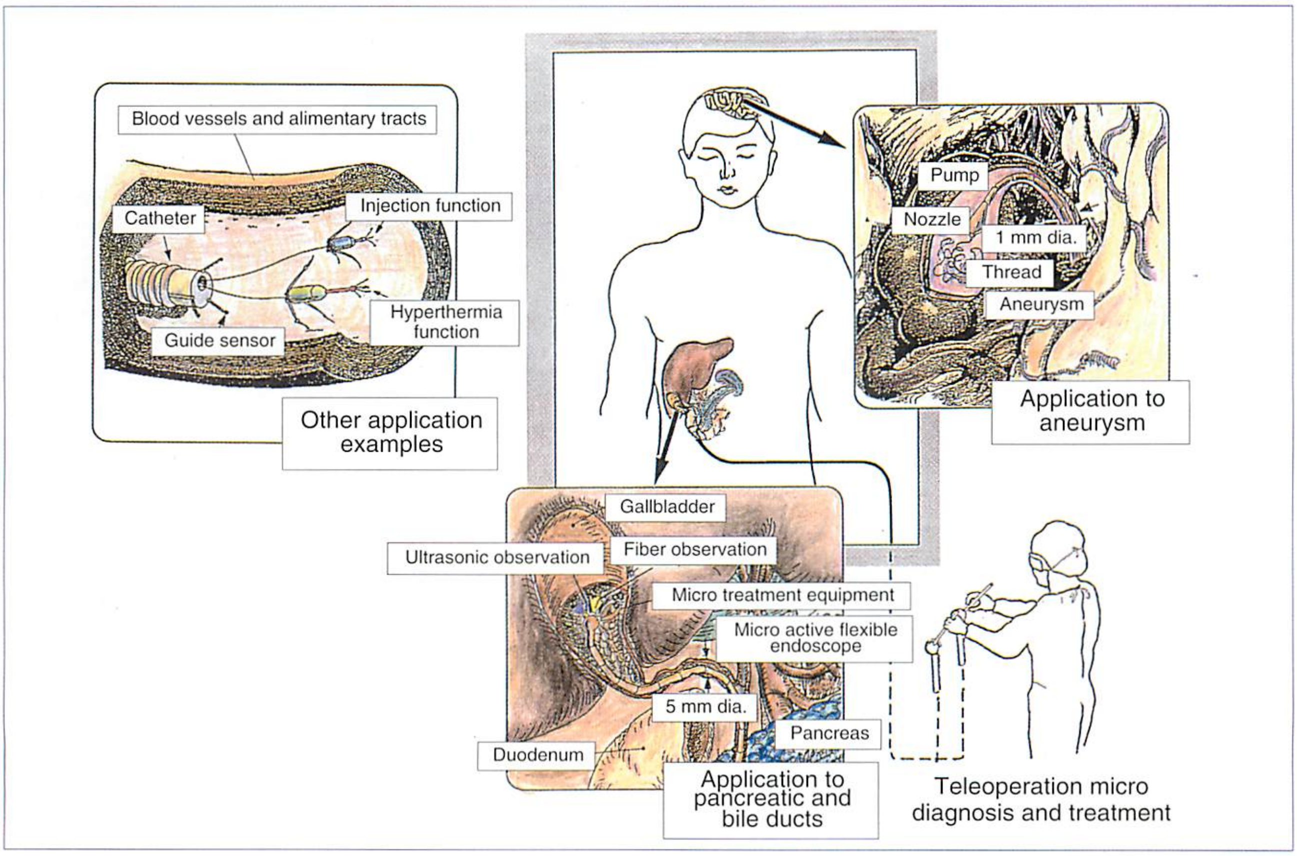

Fig.2 Development of system technology for internal diagnosis and treatment in human body

Second International Micromachine Symposium To Be Held Soon

In the future, micromachines will feature in a very broad range of technical fields including industrial fields where sophisticated and precise facility maintenance technology is required, microfactory where micromachines are manufactured, and medical and welfare fields where micromachine technology can reduce pain and discomfort. Reflecting the importance of this potential demand, last year the Micromachine Center (MMC) held its first International Micromachine Symposium to promote and disseminate micromachine technology. Because of the resounding success of this Symposium, the Second International Micromachine Symposium is being organized for this year.

This second symposium will present the results of research and development into micromachine technology in Europe and the United States, information on applications, and measures to promote micromachine technology. This year coincides with the start of Phase II of the 10-year project "Micromachine Technology" of the Industrial Science and Technology Frontier Program promoted by the Agency of Industrial Science and Technology of Japan's Ministry of International Trade and Industry. To mark the start of Phase II, presentations will introduce the project and its future applications, and opinions will be exchanged between Japanese and overseas researchers.

The Symposium will consist of seven sessions. On the first day, Professor Yoshio Tsukio of The University of Tokyo will open the Symposium with a keynote lecture. In the following sessions, invited Japanese and foreign speakers will present proposals for industrialization, introduction of foreign activities, and innovative research and development. The following foreign speakers have been invited:

Dr. Albert van den Berg, University of Twente, the Netherlands
Mr. Horst Forster, European Commission
Prof. Kensall Wise, The University of Michigan, U.S.A.
Prof. John Madden, Massachusetts Institute of Technology, U.S.A.

On the second day, Mr. Michio Hamano, Director for Machinery and Aerospace R&D, Agency of Industrial Science and Technology, will give a presentation on the progress of micromachine technology in the Industrial Science and Technology Frontier Program. In addition, members of MMC's R&D subcommittees will outline the R&D of systematization technology of the program's second phase, and MMC member companies will describe examples of R&D. The MMC's activities will be introduced at the end of the session.

The symposium will close at 3:30 p.m. this year so that participants can visit MST Japan '96, which will close at 5:00 p.m.

Relevant Information

Venue: Science Museum
2-1, Kitanomaru Koen, Chiyoda-ku, Tokyo
Tel: 03-3212-8485

Date: Oct. 31 and Nov. 1, 1996

Sponsors:
Micromachine Center
Japan Industrial Technology Association

Supporters:
Ministry of International Trade and Industry
Agency of Industrial Science and Technology
New Energy and Industrial Technology Development Organization

Cooperating Organizations:
Federation of Micromachine Technology
Micromachine Society (Tokyo)
Research Committee on Micromachines (Nagoya)
Japan Robot Association
Japan Power Engineering and Inspection Corporation
The Japan Machinery Federation

Participation Fee:
¥ 15,000 (including proceedings and reception party)

The First International Micromachine Symposium

MICROMACHINE No.17

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