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MICROMACHINE

MICROMACHINE CENTER

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No. 30

Contents

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View on Year 2000 at the Beginning of the Year

Shinichiro Ohta
Director-General, Machinery and Information Industries Bureau,
Ministry of International Trade and Industry

I would like to express our pleasure for greeting the new year of 2000.

Our economy is steadily but slowly improving as a result of the spread of the effects of various policies, but the recovery has not yet reached an autonomous stage supported by demand from the private sector. Thus, the fate of the Japanese economy is supported by the mechanical industries that drove the Japanese economic growth, such as the automobile industry, the electric and electronics industry, and the industrial machine industry. In addition, the information industry has a large latent market and will have a considerable influence on management of other fields including non-manufacturing industries. I will watch over the actual conditions of the economy very carefully with the recognition that future development of the mechanical information industry is very important for regeneration of the Japanese economy.

In November last year, the government set out a new economic formation policy with the aims of fully setting the Japanese economy on the right recovery track by changing public sector demand to private sector demand and by building a new development foundation for the 21st Century. This economic policy is the guideline for future economic management based on the concepts of establishing a new idea for 21st Century society and creating a trigger for improving the foundation, not just stopping at a short-term economic recovery policy.

The fiscal year 1999 secondary supplementary budget that was based on this idea includes policies for promoting computerization support businesses such as venture businesses and small to medium scale enterprises and various technological development projects that will play a pilot role for millennium projects. I understand that the first step in regenerating our economy is to implement these policies quickly.

In addition, since this is the first year of the new millennium, we are seriously tackling the following four objectives including the actualization of the fiscal year 2000 budget that was decided by the Cabinet Meetings at the end of last year.

The first objective is computerization for improving efficiency and development of the entire economy and society. Computerization of the economy and society is the key for strengthening international competitiveness and economic regeneration in this “digital revolution” that is rapidly approaching. To achieve this objective, we are tackling various policies to promote computerization using “improvement of the foundation in information economy,” “fostering computer-literate personnel”, and “promotion of information technology development” as the skeleton.

Regarding “improvement of the foundation in information economy,” we will proceed to improve the environment for confident and safe electronic commercial transactions including computerization of administration (actualization of electronic government), improvement of the regulations related to electronic signatures and authentication, security measures, and private information protection measures.

Regarding “fostering computer-literate personnel”, we will make efforts to foster personnel capable of utilizing information in various levels of the nation through content development techniques for schools, and by development of computer-literate personnel fostering curriculum for adults in order to secure personnel who will carry the advanced information communication society. In addition, we will improve the environment for promoting strategic computerization for middle-level enterprises and small to medium-size enterprises in order to strengthen the competitiveness of our industries.

Regarding “promotion of information technology development,” we will provide various supports to promote development of computing, devices and networks, which are important objectives in information technology.

The second objective is to create new industrial fields with high added value. For creation of new industrial fields, the aviation and space field, the new manufacturing technological field, and the medical and welfare field are expected to grow rapidly in the future in the mechanical information industry, in addition to the information communication field.

In particular, early realization of further advancement of the Japanese aviation industry with Japanese-oriented airframe development is becoming urgently necessary to cope with the structural change of the international aviation industry. To achieve this objective, we are aiming to develop innovative system integration foundation technology such as developing the technology (avionics) for a quantum leap improvement in aircraft transportation efficiency and establishing Japan’s specific technological standard that can be utilized worldwide.

The third objective is construction of an economic system responding to the environmental restrictions and resource restrictions that are imposed as a result of economic development. In practice, we will tackle various examination activities and dissemination and enlightenment activities for the full-scale enforcement of the Household Electrical Goods Recycle Law in fiscal year 2001. In addition, we will promote development of innovative recycling technology for breakthrough towards future construction of a recycling type economic society. Practically, we are considering development of fundamental technologies that can be applied to a wide range of products, such as development of a design support database system in recyclable type products in the planning and design stages and development of manufacturing technology in recyclable plastic products that produce less waste.

The fourth objective is alleviation of regulations and system reform. Regarding standards authentication, reformation of laws was implemented last year for measurement systems, etc. in order to handle international mutual approval and convert to a system based on conversion of the private sector of self-verification and inspection. We continually review the laws and regulations in terms of minimization of the range associated with Japan and international coordination and take necessary actions such as revision of ordinances.

In conjunction with these measures, we will devote ourselves to the implementation of measures for enhancing the manufacturing foundation and smoothly enforcing the special provisional law regarding industrial activity regeneration. Through the support of enterprises that are diligently tackling reconstruction of business, we will make our full efforts for economic recovery and at the same time we will devote ourselves to further development of the mechanical information industry, as we focus on the next generation and the resulting regeneration of the Japanese economy.

I would like to conclude my greeting by wishing you much happiness for the new year.

Laboratory Introduction

Professor Nuio Tuchida
School of Engineering, Information and Control Engineering Department,
Toyota Technological Institute

1. Introduction

The Electronic Control Research Laboratory is involved with studies related not only to system control and sensors but also to the devices for converting electric and mechanical energy. The former comprises the studies of a parts mating robot system for moving objects, a system of non-interference multiplex transmission of sensors and actuator control signals, and a system of measuring anisotropic permeability in an extremely small range, while the latter consists of the studies of high-torque, high-efficiency induction motors with variable power factors, axial-coil micro motors with a high-torque density, micromachines using an ion drag force, including solar microboats, micromotors, and micropumps. The following deals with micromachine-related matters.

2. Microactuators using Ion Drag Force

Hydraulic cylinders and hydraulic motors are mostly used as actuators for applications where a large force is required. A far-reaching effect can also be expected in the field of micromachines if a high-efficiency microactuator that employs fluid is realized.

A switching circuit or a commutator/a brush is required to switch the direction of current to produce a unidirectional force in conventional motors driven electromagnetically.

In biomotors with muscles and flagella, however, no such device can be found and something sophisticated is therefore considered to have been incorporated in the mechanism of a biomotor.

The author, with a keen interest in the unique action of a biomotor as described above, has devised an ion drag actuator that requires no switching circuit, by dexterouly taking advantage of ionic behavior, based on a brand-new principle. The ion drag actuator, with electrodes dipped in insulating liquid, accelerates ions in the liquid, causing the liquid to flow as a result of the tenacity between ions and the matrix liquid. The pressure produced then drives an actuator. It is generally considered to be difficult to obtain a continuous accelerating force by multistage electrodes. In particular, it was impossible to realize a rotating motor.

However, a solution to this problem has been found. As shown in Fig. 1 by linear expansion, the ion-dragged motor introduced herein is composed of electrodes that prevent the exchange of electric charges between ions and the electrodes by forming an insulating (SiO) barrier layer on half of one side of the electrode and employs a bipolar substance, ready to turn into negative and positive ions, as an ion source.

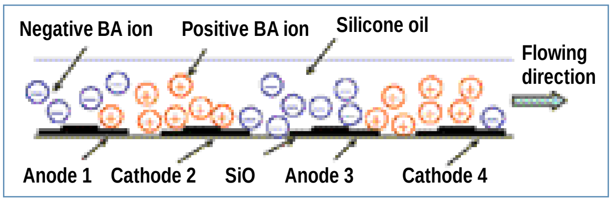


Fig. 1 Principle of producing unidirectional flow

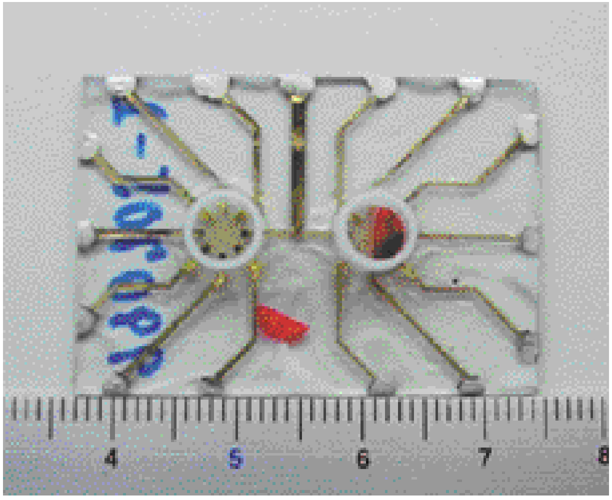


Fig. 2 Rotating ion drag motor

When positive/negative voltage is applied alternately, as Fig. 1 shows, bipolar butyl alcohol molecules are turned into positive BA ions on contact with the exposed part of electrode 1 kept positive, with the resulting ions accelerated toward the nearest electrode 2, kept negative. However, the left side of electrode 2 with SiO, an insulator, evaporated thereon, prevents the exchange of electric charges. Most of the opposite polar ions (positive) that gathered can therefore be considered to move to the exposed part of electrode 2 together with the ion-dragged flow of liquid. However, butyl alcohol loses its electric charges at electrode 2, kept negative, followed by instantaneous conversion to negative BA ions. Those negative ions are accelerated toward the nearest right anode 3 instead of moving toward the left side from which they came. With similar phenomena occurring continuously and in succession, butyl alcohol molecules are accelerated in a unidirectional manner toward the right side while they are turned alternately into positive and negative ions. This produces a dragging force between the ions and the matrix liquid, silicone oil, causing the liquid to flow.

If voltage is applied, to the electrodes attached in a radial manner with cylinders poured an insulating liquid containing bipolar substances as Fig. 2 shows, the liquid flows rotationally. Then, if the rotor is submerged in the liquid, the rotor gains a turning force to rotate. As described above, the motor differs from conventional electrostatic or electromagnetic motors, and is quite unique in that it requires no switching circuit. It is available now with approx. 3,500 rotations per minute. Also available is a motor in which the rotational direction can be freely controlled purely electrically by rendering the insulator-covered part of the electrode as an independent auxiliary electrode.

On the other hand, when positive/negative voltage is applied alternately to multi-layered wire nets covered with insulators on one side as Fig. 3 shows, a pump action can be expected in a similar manner as described above. This pump is suitable for miniaturization because it is simple in structure and requires no mechanically movable parts and can obtain pressure directly from the electric field. It also enables the electrical reversal of the direction of pressure application by providing an independent insulator-covered electrode as in the rotating motor described above.

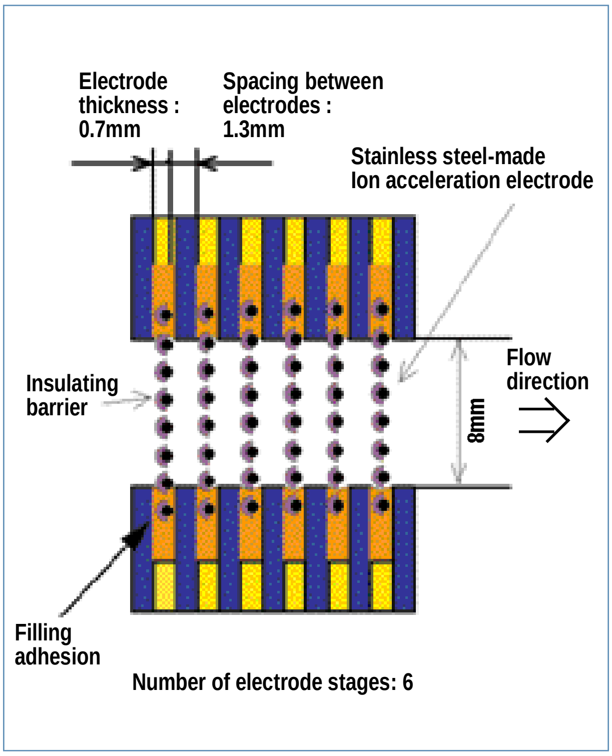


Fig. 3 Structure of an ion drag micro-pump

3. Solar Microboats

In addition to the above 2 actuators, a solar microboat (MSB), which utilizes an ion-dragged liquid flow similarly, is also under investigation. This boat can swim about under water like bacteria or water insects.

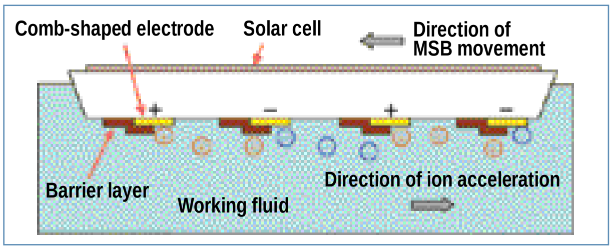


Fig. 4 Cross section of a solar microboat

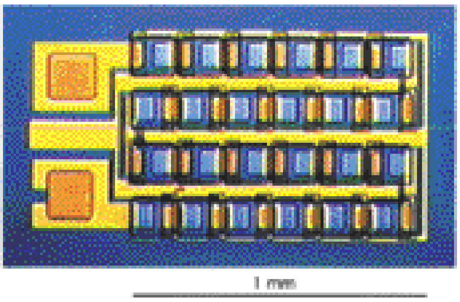


Fig. 5 A series of 24 solar microcells on the upper surface of an MSB

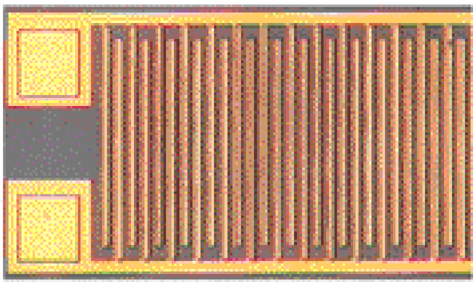


Fig. 6 Ion acceleration electrodes on the lower surface of an MSB

As the schematic diagram of the MSB in Fig. 4 shows, the MSB gains energy from the solar cells installed on its upper surface, while the multistage acceleration electrodes on its lower surface accelerate ions and the resulting reaction force propels it. Figs. 5 and 6 show, respectively, solar cells installed on the upper surface and a comb-shaped ion acceleration electrode. Since a series of 6 solar cells was proven to move an MSB, the author is aiming to realize a movable at more than several mm per second MSB with 24 solar cells connected in series.

The author also hopes to fabricate an electronic circuit and sensors for installation on the MSB in the future, thereby realizing a system that can be freely controlled from outside by applying a semi-digital non-interference SS multiple transmission mode now under development.

Results of Industrial Science and Technology Frontier Program
“Research and Development of Micromachine Technology”
(4 Experimental Systems)

Experimental system for Micro Processing and Assembling

1. Introduction

The experimental system for micro processing and assembling aims to study the technology of systematization for the realization of “a microfactory” as one of the applications of micromachine technology. Seven companies, i.e., Aishin Cosmos R&D Co., Ltd., Seiko Instruments Inc., Hitachi Ltd., Fanuc Ltd., Fuji Electric Research Institute Inc., Mitsubishi Cable Industries, Ltd., and Yasukawa Electric Corp., are jointly conducting this study. The experimental system, roughly of desktop size, consists of a processing unit, an assembling unit, and a conveyance unit. Fig. 1 gives an image of the experimental system. The concept of the system lies in “multi-process integration”, namely, to do complicated work with plural functions (processes), incorporated in the system and interrelated with each other. This system enables the processing of a gear with an axis.

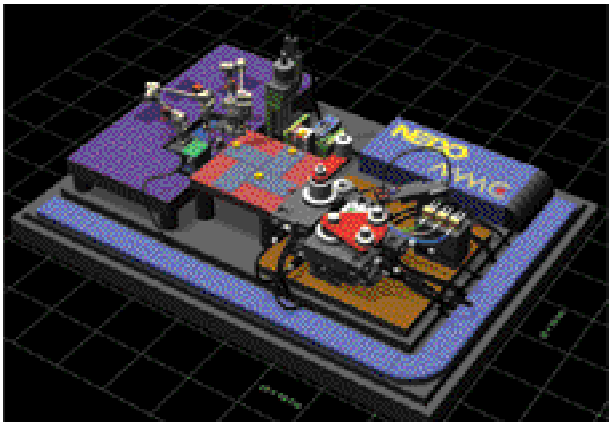


Fig. 1 Image of the Experimental System for Processing and Assembling

2. Development Conditions of the Experimental system

Fig. 2 gives the photos of the primary experimental system and major devices.

2.1 Processing unit

In the processing unit a processing probe is brought close to the metal substrate, provided in the processing cell, to apply voltage to it to carry out electrochemical etching. Any mold with an optional pattern can be manufactured by scanning the processing probe. A sacrificial layer is formed by plating onto the mold, followed by the manufacture of a part by electroforming. When the sacrificial layer is etched, the part can be removed from the mold. Plural processing liquids and cleaners are used for a series of those processes. A trochoid-type liquid supply pump, small in size but large in flow, and a device for observing the finishing have been mounted on this experimental system. This device, with an image scope and a tactile sensor incorporated in a catheter, 3 mm in diameter, is used for environmental recognition. To carry this environmental recognition device to a predetermined position in several microns, a motor with a built-in servomechanism is used. It has been confirmed that the inspection unit enables the observation of the shape of a gear formed after automatic exchange of processing liquids and cleaners, electrochemical etching, and electrochemical processing.

2.2 Conveyance unit

The conventional conveyance system used in the factory is usually intended for unidirectional conveyance with a belt conveyor. This method is suitable for mass conveyance along a fixed route; however, it is unsuitable as a conveyance system in a microfactory as this latter requires the conveyance of parts flexibly and in a limited space. One answer to this problem is a two-dimensional conveyance. In this experimental system, a coil diode module was constructed by covering the conveyance system with 1-mm square electromagnets. A pallet, with permanent magnets attached, can be carried by changing the electromagnets. If a pallet deviates from the preset route, this system enables the detection of the position of the pallet with CCD camera image to send it back to its original position. The resolution of positioning during conveyance is up to 1 mm, the size of an electromagnet. At the terminal of the conveyance, the resolution of positioning is ±20 μm by the positioning mechanism (Block V). It has been confirmed thus far that a part, 0.2 g in weight including a pallet, can be carried two-dimensionally according to the preset conveyance program.

2.3 Assembling unit

The assembling unit enables to hold and assemble various parts with a micro-arm with a high-torque ultrasonic motor and a high-resolution encoder incorporated. The microarm changes work tools in various ways in accordance with the work contents. The work tool mounts 3 kinds of holding devices and a coating device.

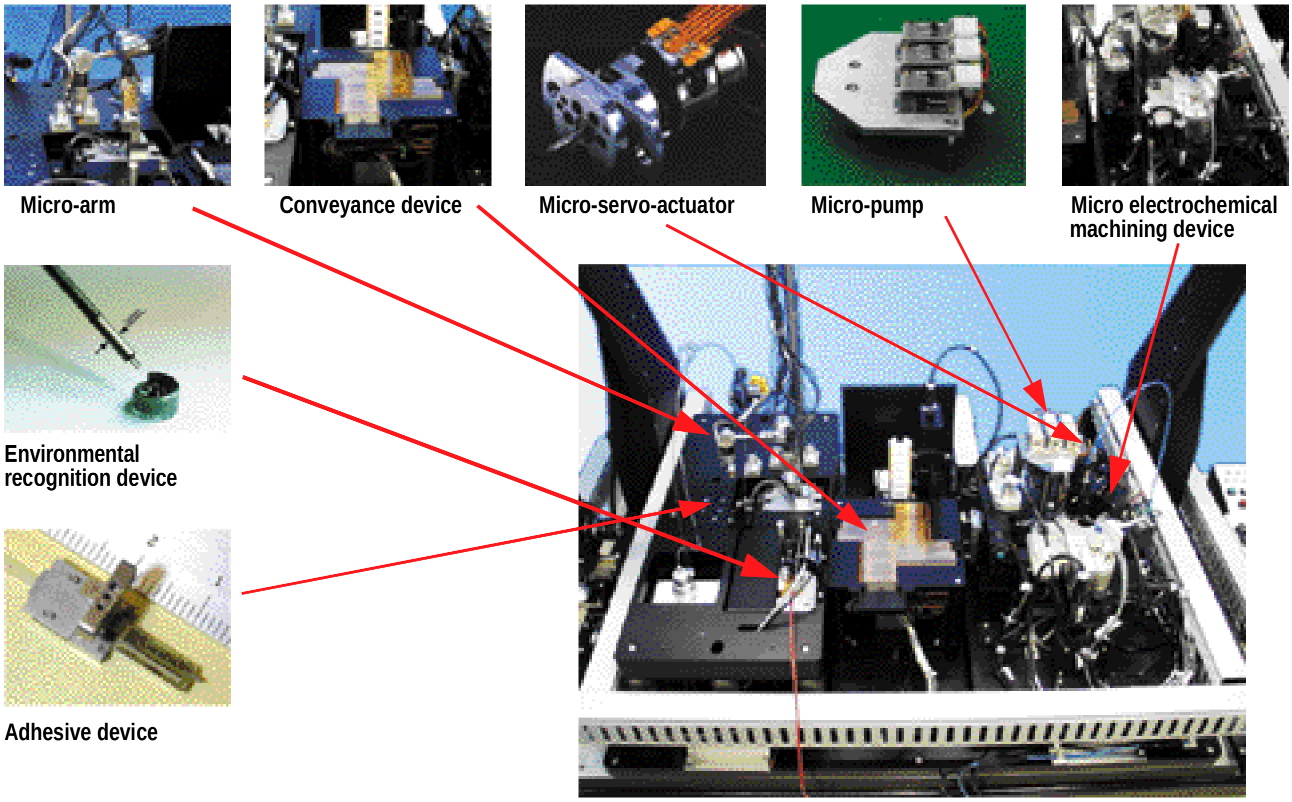


Fig. 2 The Experimental System for Processing and Assembling

A vacuum chuck is used for holding pin-shaped parts. A scroll-type vacuum pump, small in size and with fewer vibrations, is under development so as not to hinder the smooth movement of the microarm. A high power electromagnetic chuck that holds a heavy magnetic material is mounted as well as an extremely small electromagnetic chuck for holding small and light objects. The coating device fixes parts by using an adhesive, because it is difficult to use screws for fixing a small object after assembly. The coating device used for such an application is required to discharge a trace amount of adhesive. This coating device can apply trace amounts of adhesive (resolution: several nanoliters) using the diaphragm provided in the flow course. Radiating laser beam to light absorbers one after another moves the diaphragm. A stage is also required for assembly. The experimental system mounts a rotary stage with a built-in microservo-actuator. With those devices working together, it becomes possible to assemble extremely small parts. To date, it has been confirmed that the coating device, the assembly stage, and the microarm, when linked together, enable the application of a trace amount of adhesive, that the electromagnetic chuck and the microarm enable extremely small gears to be held, and that the environmental recognition device and the assembly stage enable the observation of an object.

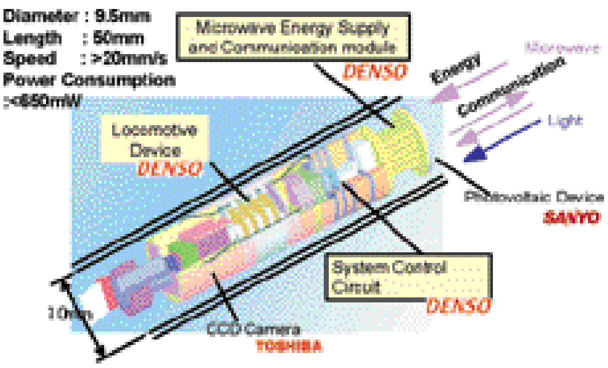
3. Conclusion

Emphasis was placed on the introduction of the functions of the major units of the experimental system for micro processing and assembling. To date, each device has been confirmed qualitatively to exhibit respective major functions in the system. Simultaneously, it has also been clarified that the magnetism, light, and heat produced by one device influence the other devices to varying degrees. Hereafter, the writer is planning not only to grasp the functions of respective devices and units quantitatively, so that the problems posed and their countermeasures can be checked but also to carry out evaluation of the effects of energy conservation.

Development of Experimental wireless micromachine system for inspection on inner surface of tubes

1. Introduction

In the Industrial Science and Technology Frontier Program, three companies, namely, DENSO Corp., Toshiba Corp., and Sanyo Electric Co., Ltd., are involved in the research and development of an experimental wireless micromachine system for inspection on inner surface of tubes. This system is equipped with functions to take pictures of the wall inside a tube and to radio-transmit them while travelling inside a thin tube, 10 mm in inside diameter, by wireless. Microwaves and light supply the energy required for the system. This system is composed of an environment-recognition device and is mounted with a CCD element, a locomotive device for travelling inside the tube, a communication control circuit for communication with outsiders and for system control, a microwave device for the supply of wireless energy and communication, and a photovoltaic device. Thus far, devices for mounting have been developed, and in fiscal 1999, three subsystems incorporating plural devices have been developed as the first step towards systematization (primary prototypes, A, B, and C).



Experimental wireless micromachine system for inspection on inner surface of tubes

2. Conditions of development of the primary prototype system

a) Type A

An experimental system of type A was developed to verify the following functions: in-tube movement by wireless, and start, stop, and direction shift by command control. This system is equipped with a locomotive device, a communication/control circuit, and a microwave device. For miniaturization, the circuit is assembled with bear chips, which are mounted in high-density on its substrate, utilizing flip-chip interconnection technology. In this system, an antenna was developed that complies with two microwave frequencies so that both energy supply and communication can be rendered possible by microwaves to verify command control communication when energy is supplied.

b) Type B

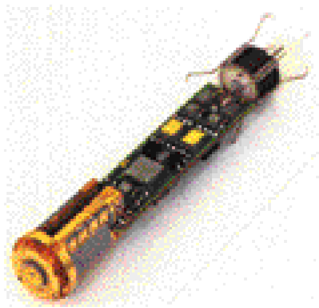
An experimental system of type B was developed to verify simultaneous energy supply by light and microwaves. This system mounts a microwave antenna integrated with the photovoltaic device developed by Sanyo, and a voltage stabilizing circuit. With the development of an antenna with a new structure so devised that the photovoltaic device will not significantly lower the receiving efficiency, a simultaneous energy supply has been realized by light and microwaves.

c) Type C

An experimental system of type C was developed to verify the function of image transmission by microwave communication. This system mounts an environment-recognition device developed by Toshiba and a communication control circuit developed by DENSO. A frame memory is usually required for image transmission. It was found, however, that in such a circuit, the chip becomes too large to be mounted. A mode was therefore devised in which image data from a CCD camera are divided into packets for transmission. This resulted in realizing the wireless image transmission of 3 frames per second after successful development of the world's smallest chip, about 4 mm square, capable of transmitting images.

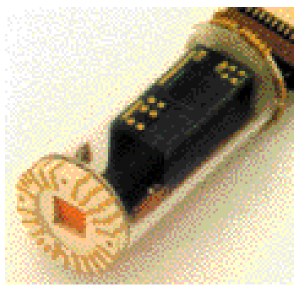
3. Conclusion

Through the development of the primary prototype systems, their functions were verified along with the extraction of their accompanying problem. Those problems were found to be the methods of electromechanical connection between the devices, heat generation, and electric noises. In the future, development of a secondary prototype system with all the system functions incorporated will be initiated by taking the foregoing into consideration.



Type A trial manufacture system

Type B trial manufacture system (Antenna part)



Type C trial manufacture system (Environment-recognition device part)

Chain-type micro-machine system for inspection of outer tube surfaces

1. Introduction

A number of slender tubes are arranged at small intervals in the heat exchanger of a power plant. A micromachine (a component micromachine) for inspection on outer surfaces of those slender tubes should be miniaturized so that it can pass through the narrow spacing between the tubes. Therefore, it is difficult to equip the micromachine with many functions. On the other hand, however, it becomes necessary for inspections to cover a comparatively large area and satisfy a variety of functions. The concept is therefore required of a multiple distributed micromachine system to satisfy those opposing requirements. In this system the necessary functions are distributed between many component micromachines and the task is carried out cooperatively by the micromachines. In the MITI's micromachine project, such a chain-type micro-machine system for inspection of outer tube surfaces, as described above, has been jointly developed by three companies, i.e., Sumitomo Electric Industries, Ltd., Matsushita Research Institute Tokyo, Inc., and Mitsubishi Electric Corp. since fiscal 1996.

2. State of Development of the Experimental System

Fig. 1 shows the appearance of a developed prototype of the component micromachine. As the figure shows, the component micromachine consists of four devices with each function: a driving device, a travelling device, microconnectors, and a flaw detection device. The machine, 5 mm in length, 9 mm in width, and 6.5 mm in height, can travel horizontally and vertically with six magnetic wheels. It can also be automatically connected to and separated from the adjoining component micromachine by the microconnectors with electromagnets arranged upper right and left. Its main devices are outlined below:

The driving device is a radial-gap type cored electromagnetic motor, 1.6 mm in diameter and 2 mm in length. It was miniaturized by employing minute process coils fabricated using high-aspect-ratio multilayering technology and rotates at 40,000 rpm.

The travelling device, 5 × 5 × 1.5 mm on one side, mounts a planetary gear system, with a reduction ratio of 1/200, fabricated by micro electro-discharge machining, and permanent magnetic wheels. The permanent magnetic wheels enable a strong traction force to be attained by the magnetic attraction between the wheels and the travelling surface. This went so far as to demonstrate that the device can push a one-yen coin (1 g) double its own weight (0.42 g) and travel at a high speed of 10 mm/s by the wheel driving mechanism considered disadvantageous to micromachines.

The microconnector, 3 mm in diameter and 2 mm in thickness, is an electromagnetic connector. Its terminal part, with minute terminals fabricated by deep X-ray lithography, supported by gimbal springs, can be inserted and pulled out by moving the permanent magnet mounted inside with electromagnet. It can remain connected by the permanent magnets without power supply except when used for connection and separation. Fig. 2 shows how the microconnectors are connected and separated automatically.

It was also demonstrated that three driving machines (with driving devices) can pull up and down seven connecting machines (without driving devices) when both of them are connected with the microconnector around a slender tube, 22 mm in diameter (Fig. 3).

3. Conclusion

The final target, which includes narrow space movement and flaw inspection on outer surface of the slender tube by moving multiple connected micromachines around a slender tube, will be realized in near future. The accompanying fundamental technology will be also established.

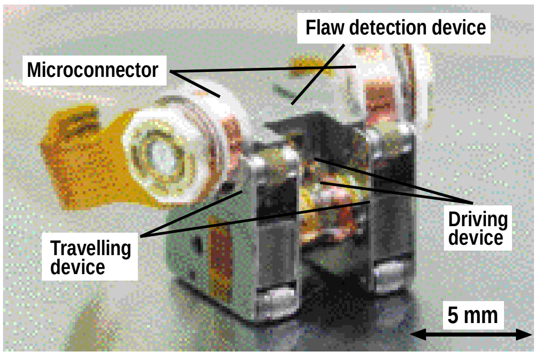
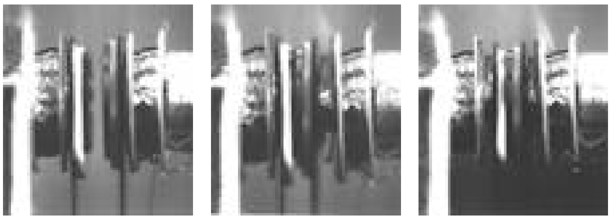


Fig. 1 Prototype of component micromachine



(a) Separated state (b) Excited state (c) Connected state

Fig. 2 Movement of microconnector

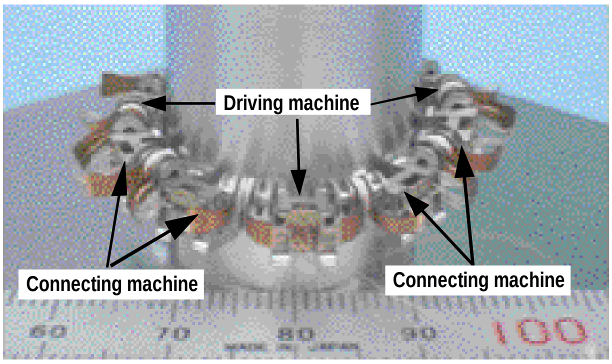


Fig. 3 Movement of multiple connected micromachines around the slender tube

Experimental Catheter-type micromachine system for repair in narrow complex areas

1. Introduction

The experimental catheter-type micromachine system for repair in narrow complex areas is the first step system to develop into micromachines for in-machine repair, which enters inside the complicated machine without disassembling to carry out inspection and light repair work. Three companies, i.e., Olympus Optical Co., Ltd., Omron Corp., and Murata Mfg. Co., Ltd., are jointly engaged in the research and development of this system. The primary target of this research lies in establishing the technology of operations in a narrow space the enable the measurement of a minute-size defect and its repair. The second target is to establish the technology of integrating the many required functions, for instance, for inspection and repair inside a steam turbine as possible work in a narrow space, into the head of thin tubes in the longitudinal direction.

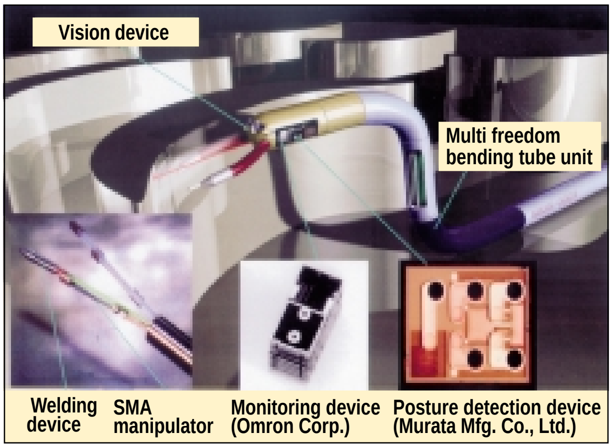


Fig. 1 Experimental catheter-type micromachine system for repair in narrow complex areas (Conceptual)

2. Status of the Development

2.1 Development of Devices

Table 1 Functional devices developed by respective companies

Device name	Target specification
Multi freedom bending tube unit	Outside diameter: 8 mm; Number of bending parts: 3
Manipulator for repair	Outside diameter: 3 mm
Welding device	YAG laser welding; Outside diameter: 3 mm
Posture detection device (Murata Mfg. Co., Ltd.)	Size: 4.5 × 1 × 3.5 mm; Sensitivity: 1°/sec
Monitoring device (Omron Corp.)	Size: 4.5 × 2 × 4 mm; Defect detection resolution: ≥ 0.5 mm (at 50 mm)

Table 1 shows the functional devices that each company is responsible for developing, and the targets of development.

2.2 Systematization Technology

2.2.1 Development of thin tube integrating technology; MIF mounting technology

As the technique of mounting functional devices in high density, including the monitoring and posture detection devices, a technique of mounting is under development utilizing the multifunction integrated film technology (MIF) developed in the 1st term.

First, the functional device is mounted onto a silicon wafer, in which the integrated circuit is formed for driving the functional device, and then a planar mounting module is made after removing the unnecessary silicon part by etching. Each functional device is arranged three-dimensionally by folding this module. This MIF technology is considered to offer the optimal method for mounting micromachines, a method of arranging functional devices and their peripheral ICs in various directions in a small space three-dimensionally and in high density.

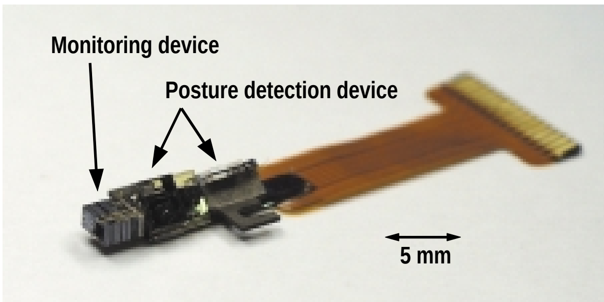


Fig. 2 Photograph of the electronic unit using MIF mounting technology

2.2.2 Development of narrow area repairing technology

Laser welding was selected as the work to be performed by this experimental system, which enables non-contact work to be performed with comparatively little thermal influence on the system. So far, reduction of stray light and a cooling mechanism have been developed. It was then confirmed that laser welding is capable of welding a SUS plate to a depth of 0.5 mm or more. At present, after trial making of the experimental system, evaluation of the repair performance of a repair unit with the SMA (Shape Memory Alloy) manipulator and the welding device, is under way.

3. Conclusion

Next fiscal year, the final experimental system will be made and evaluated. Through this experimental system, the studies of the thin-tube integration technology, that is, the technology of mounting micromachines of high density will be continued and the possibility of the manufacture of micromachines capable of "doing work" will also be investigated.

The Fifth International Micromachine Symposium

The Fifth International Micromachine Symposium was held on October 28 and 29, 1999, at the Science Museum in Kitanomaru Park, Tokyo.

At the opening on October 28, Mr. Shin-ichiro Oota, Director-General, Machinery and Information Industries Bureau, MITI, Mr. Kouji Kajimura, Director-General, AIST, MITI and Mr. Hideyuki Matsui, Chairman of NEDO gave guest speeches. Participants registered for the two days totaled 421.

At the beginning of the first day, Professor Emeritus Takemochi Ishii, The University of Tokyo, gave a special guest speech titled “What micromachines will produce in the 21st Century.” The theme of the lecture was the role of micromachine technology and the expectations in the large current of technological civilization called digital computerization. The speech was very interesting and inspiring, covering many areas including the characteristics of Net Generation, nefootwork (new concept combining footwork and network), increase of meme pool as a result of digital computerization, and the road to micromachine. The manuscript of the lecture that was inserted in the symposium preliminary report that was distributed that day is attached from the next page. Please read it.

On the first day, apart from Prof. Ishii, 16 guests including five from abroad (one read by another) were invited as guest speakers. Each gave impressive speeches.

Guest speakers from abroad:

Dr. Franz van de WEIJER / NEXUS
Ms. Karen W. MARKUS / MCNC
Dr. Francois GREY / Technical University of Denmark
Dr. Ronald B. ZMOOD / Melbourne Institute of Technology
Prof. Nico F. de ROOIJ / University of Neuchatel (read by the chairman)
Dr. Chih-Ming HO / UCLA
Prof. Chang-Jin “CJ” KIM / UCLA

In Session 5, “Thinking of Micromachines,” the unique content appealed to the audience. You can read the speeches in the following pages.

The second day was dedicated to presentations on the progress of “Research & Development on Micromachine Technology” which is the national project of Industrial Science and Technology Frontier Program. This was followed by an overview from Mr. Yoshikazu Yamaguchi (Director for Machinery and Aerospace R&D, AIST, MITI), and introductions to researches conducted in the three national research laboratories, including the Mechanical Engineering Laboratory, AIST, MITI. Next, a presentation on the progress of the second phase of the micromachine technology project was made by Mr. Tatsuaki Ataka, chairman of the Research Committee of MMC. Technology trend survey results were announced by four working group heads of the Research Committee. Another seven presentations were given on results from ISTF.

The seminar received high evaluation through the answers to questionnaires that were given to the participants in the venue at the end of the symposium regarding the plan and contents of the lecture. We had to change the sequence of the lectures due to some incidents that occurred on that day such as a transport accident. We sincerely apologize for any convenience.

The next symposium is scheduled for the following date and location:

The 6th International Micromachine Symposium
Scheduled Date: November 9 (Thu.) and 10 (Fri.), 2000
Scheduled Location: Science Hall (Science Museum B2F), Kitanomaru Park, Tokyo

A photo taken at the scene of The 5th International Micromachine Symposium

What Micromachines Will Produce in the 21st Century

Takemochi Ishii
Professor Emeritus, University of Tokyo

1. Introduction

One may logically associate the title "What Micromachines Will Bring in the 21st Century" with the progress, development, and popularization, of micromachines over a considerably long period (at most about 100 years) and the overall effects that one can foresee these micromachines having, on industry, society, lifestyles, and culture. However, tackling this issue head on would give rise to too many problems, as one would have to make difficult predictions about the future.

In this document, therefore, I will employ a relatively bold approach in methodology incorporating the following restrictions. First of all, I will be making assumptions mostly for the first half of the 21st century, because the second half is several decades away and therefore is still too uncertain and involves too many unknown factors. Predictions regarding micromachines can quickly lose their usefulness, since such fields as data communications and biotechnology, which are closely related to and have a strong effect on micromachine technology, are expected to continue their rapid growth for some time. Hence, publications on these subjects will rapidly become outdated, and research reports giving future forecasts will become nothing more than historical documents for the period in which the research was conducted. This is not to say that such reports will become worthless, as historical viewpoints themselves are of course extremely important. Ultimately, I hope to capture the historical trends of technological civilization in this document from a macro viewpoint. With this approach, I assume that micro revisions to our predictions will occur continually with the frequent additions of individual accomplishments in technological (micro-technological) development. As a result, we cannot avoid a strong influence of temporary undertakings, or "working hypotheses".

Nevertheless, we must first conduct a macro evaluation of micromachines in the history of technological civilization. In plain terms, the issue is whether micromachines will be the key to creating a new mechanical civilization in the 21st century, and whether humankind, as homo faber (man the maker), will transcend the realm of existing industrial products and enter a new age of creating a new type of machine. The drive to create new machines to replace the old probably stems from the fact that we are now caught up in a digital information evolution (perhaps the greatest change since man began walking upright). To achieve this evolution we will require appropriate new tools and machines, which will inevitably accelerate the technological innovation.

2. The Digital Information Age and the Net Generation

In modern industrial technology, the precision of machine tools, which are "tools for creating tools", determined the limits of precision for the entire system. In light of this fact, the use and popularization of numerical control (NC) machine tools was an extremely important development. NC machine tools employ digital numerical displays to assure product precision. These not only helped us increase the uniformity of product quality and improve non-cost related competitiveness, but also enabled us for the first time to perform high-precision numerical calculations needed to produce complex curved surfaces such as metal dies for forming nonspherical plastic lenses. These represent a qualitative change called the mechatronics production technology revolution. It also became possible to improve the efficiency of unmanned industrial robots used for such processes as welding and spraying and to break new ground in the field of advanced precision processing with these robots.

At the same time mechatronics was progressing, we witnessed striking technological progress in digital data communications, as well as the downsizing of such electronic components as semiconductor ICs that helped launch the PC age. In addition, it became possible to connect multiple PCs to a data network such as the Internet, which was a groundbreaking accomplishment. This gave rise to an autonomous distribution network system to replace conventional systems having small stand-alone computers isolated from one another. This development has even had a great influence on our everyday lifestyles.

Technological civilization in the first half of the 21st century will undoubtedly be influenced by characteristics of the Net Generation, that is, people raised in the 21st century environment in which this type of network is taken for granted as part of the social infrastructure. Recent surveys have released at least two specific traits of this Net Generation. First, with the rising use of e-mail, there has been a clear increase in mobility, and users are travelling to meet with others and attend gatherings. This is quite different from the image of a computer nerd alone in a room, engrossed in a desktop PC. In fact, we are seeing a rapid increase in the number of people buying portable information devices such as notebook PCs, pointing toward a strong trend in mobile computing.

The second characteristic of the Net Generation is a fondness for performing multiple processes simultaneously. For example, the mobile users described above do not have to concentrate solely on getting somewhere, which I will call "footwork," but can work simultaneously at an information device connected to a network. Hence, they need not choose between concentrating on footwork or working on a network, but can perform both. Just as "sound" requires the simultaneous recognition of frequency and duration to exist, the single word mobility seems better served to include both meanings of footwork and network. In fact, it may be more appropriate to use the term "nefootwork" (coined by the author) in place of mobility to stress the new concept (in contrast to the division of labor and specialization inherent in industrial society).

Desktop computers, which until now have occupied the mainstream, require their users to sacrifice mobility (footwork). These computers employ a graphical user interface (GUI) to enable a user to work on a network. A device suited for nefootwork, on the other hand, would likely use a perceptual user interface (PUI), an interface that gathers environmental data using auditory or other sensory data in addition to visual data and accepts diverse input such as voice rather than keyboard entry. This interface is more likely to satisfy the second characteristic of the Net Generation described above, their fondness of multitasking, by freeing up their hands for other operations. Naturally, PUI will not completely eliminate the use of visual displays and manual input. It can be thought of as an extension of GUI. The relationship between mobility, the first characteristic of the Net Generation, and PUI more clearly illustrates how PUI expands the capabilities of GUI. This relationship will be explained further in the next section.

3. Mobility and Virtual Reality

To achieve the downsizing of PCs that gave rise to notebook and palmtop PCs, it was first necessary to develop the high precision processing technology described above for producing hardware and to speed up product development in order to meet the marked demand. Although this downsiz-ing was certainly an important technological achievement in hardware to support mobility, the first characteristic of the Net Generation, reducing the shape and proportions of the equipment merely achieves a miniature GUI model, which does not in essence contribute to mobility. A keyboard so small that the user cannot operate it with his fingers, for example, is not feasible for mobile computing. The Data Glove (brand name) may be more effective than a keyboard, as it allows the user to input data using a glove containing sensors to detect finger movement. The basic concept of the Data Glove, developed in the beginning stages of virtual reality (VR) research, is extremely unique in that spatial movement of a body (a portion of the body in this case) is detected and converted to digital data. This method is generally referred to as motion capture. As those of the Net Generation know, this process has recently been applied generously and with great effect in computer graphics design for fighting scenes in video games. With the motion capture approach, the relationship between motion in the real world, such as that of a finger or the entire body, and the digital data that represents this motion is equivalent and dual. Although developed as a data input interface for VR applications, the Data Glove eliminated any restrictions to mobility inherent in all keyboards since the mechanical typewriter in principle. Hence, it was important for us to understand that rather than downsizing hardware, digitization of data with motion capture software and the like is a fundamental condition for achieving mobility.

Another tool typically used for VR is the head mounted display (HMD), which has been around for quite some time. This display is more suitable for the mobile user than are fixed displays in principle. However, there is a lot of room for improvement in reducing the size of current HMDs. Still they could be very useful mobile tools in the 21st century should we succeed in reducing their size.

In short, VR I/O devices such as the Data Glove and the HMD described above contain GUI functions and support mobility, proving that they expand the functions of GUI. Now, let us try to further imagine the information environment of the 21st century surrounding the Net Generation as it relates to the connection between VR and PUI. It has been predicted that the standard PC being used at the end of the 20th century will soon become obsolete. Certainly, various functions now performed by these PCs will most likely still exist in various forms, but the current GUI PC will ultimately die out to be replaced by PUI-type formats. On the other hand, VR will become commonplace, as the Net Generation will have grown up with video games and will be familiar with their advanced graphics. There will be more emphasis on access to live, unfiltered information from the source through nefootwork devices. At the same time, nefootwork devices will enable us to access digital information from the network while in the field and to communicate directly (even with images) with remote locations. Accordingly, this will reinforce our sense of an expanded reality by overlapping layers of the reality at our current location and VR data. This is referred to as augmented reality (AR). PUI is a technology with position to support AR and naturally will also contain conventional VR.

4. Biological Foundation of the Nefootwork

Now let us consider the biological roots giving rise to the two characteristics of the Net Generation described above and link them to micromachines. First, I would like to consider the process for establishing a communication network for the first characteristic, mobility, from biological and system logic perspectives. As described above, the network (information system) with the essential meaning of footwork (movement system). The close relationship between these two systems can be understood biologically when observing a newborn child. To begin with, ontogeny is a biological law which phylogeny is repeated. Accordingly, observations of a newborn child are suggestive of portions of the evolution of humankind. Before birth, the fetus has sight and communicates with its mother primarily through direct contact with chemical substances (close contact information). After birth, however, the emphasis in communication shifts to the transmission and reception of remote data that includes sight and sound. This shift in communication can be said to correspond to the point in the phylogeny, or evolution, of humankind when the living habitat of humankind shifted from water to land. This existence of information stored in genes, such as the stepping reflex seen in newborn babies, can be considered as the biological foundation for footwork. Remote data transmission and reception is clearly advantageous for mammals that can move rapidly on four legs. Freedom of both arms and supporting their heads vertically on vertebrae enabled the enlargement of their brains. Hence, the effects produced by walking upright were added to their ability to move more quickly on the ground, or improved footwork, and the acquisition of their ability to gather environmental data from remote locations. Further, the freed hands (forelimbs) did not degenerate. Instead, in conjunction with the development of the brain, humans began using their hands to manipulate tools and create advanced objects. Humans started to walk upright when they stopped living in trees and moved to the savanna. Their claws used during their period in the trees evolved to fingernails. They developed fingerprints and palm lines and independently moving fingers with opposing thumbs. They became able to perform dexterous operations, such as grooming for lice nits and picking up single grains with their fingers. Micromachines exist far beyond this line of evolution. Genetic data alone is insufficient to cover this distance. Therefore it is necessary to accumulate data other than genetic data. This data is referred to as memes. Memes not only include software such as language, symbols, characters, numerical data, diagram, images, recordings, and computer programs, but also broad, unstipulated data and information acquired through observation and imitation.

5. Capacity to Challenge Micromachines

With memes, imitative behavior defines what gets passed on from generation to generation. Their behavior constitutes pseudo-genes, similar to the way genetic information is stored in gene pools. An example of this is the way languages are acquired by mimicking others. In general, children have a far superior capacity for acquiring language skills. Genes are handed down in a physical and hereditary manner, whereas memes achieve this through acquisition. However, it is also possible to consider the two together, to achieve a broad, overall understanding of how information is handed down through successive generations. According to observations and studies conducted over the past two years or so, Japanese children were highly receptive of nefootwork. This children's acceptance for nefootwork will expand the meme pool and no doubt greatly increase the meme activity.

The second characteristic of the Net Generation, multi-tasking, will not necessarily be welcomed by the current generation that completely adapts to industrial society (perhaps because the current generation is too accustomed to the method of dividing work and allocating one job per time slot). However, at top research institutes overseas it is no longer unusual for researchers to specialize and have doctorates in two or more fields. This is referred to as double majors or multiple majors. This second characteristic is also useful for increasing memes when there is a decrease in the number of individuals involved, such as a decrease in children. In short, the two characteristics of the Net Generation are expected to spur on an increase in the meme pool into the 21st century. Significantly, the digital data portion of the memes should be capable of self-catalytic propagation due to innovations in information technology.

Originally, information technology innovation is considered independently from spatial problems, but the two should be considered in coexistence with each other, as is stressed in the nefootwork described above. In the history of technological civilization, spatial expansion has always been inseparable from innovation in information technology (or media in the narrow sense). Some prime examples are the role print media played in the great explorations of the Renaissance period or the relationship between space development and digital information in the modern era. Moreover, the sphere of human activity is not limited to the macro-cosmos, but also spreads throughout the micro-cosmos, the microscopic world in the human body. As described above, in the process of evolution humans were able to acquire genes suitable for living in trees and for performing dexterous work with their hands. However, tackling the micro-cosmos with only the gene pool is most certainly hopeless. It will be necessary to accumulate an enormous amount of memes to cross the huge gulf separating us from the world of micromachines. Digitizing information is the first step in resolving this problem. At last micromachines have unquestionably entered our sphere of sight from a technological perspective. As seen in the nefootwork example, if the keyboard is replaced by the Data Glove and digital data culled from motion capture is used as the primary data source, we will see radical downsizing in hardware devices, and in time the PC format will be replaced by micromachines.

6. Conclusion

The field of medicine is most commonly cited for the first applications of micromachines. As during the Renaissance and the Meiji Restoration, challenges toward the micro-cosmos of the human body have spawned new developments in the science of anatomy. It is always noted that we have entered a new age whenever we discover radical changes in geometry, which is a fundamental knowledge of space, and anatomy, the internal morphology of the human body. Now, more than ever, are we getting to enter a new age. From X-CT and MRI-CT to recent optical topography, digital images have contributed enormously to medicine; and endoscopy, electron microscope confocal laser microscopy, and scanning probe microscopy are having an unprecedented impact.

These developments have given micromachines their first applications. While the progress made in hardware (precision instruments) was of course important, the development of molecular-biological software, often called bioinformatics (also targeting genome), was also indispensable - almost a type of virtual reality world.

I expect many researchers at the present symposium will introduce other new application fields in addition to medicine. Although the exact effects that the popularization of micromachines will have is not yet clear, I am certain that micromachines will be one of the most important fields of the 21st century.

Trends in Value-Orientation of Young Generation

Atsushi Kadowaki
Professor, University of Tsukuba

The Micromachine Center considers it very important to show the attractions and possibilities of micromachines to youths who will undertake the micromachine technology or will incorporate micromachines into their lives in the future. Professor Kadowaki has studied long-term changes of life styles and value orientation of youths in the Tokyo metropolitan area. This lecture discusses the result of his study regarding the value orientation and way of thinking of contemporary young people.

Outline of the Lecture

A study was conducted to regularly observe and investigate trends in the lifestyle and lifestye-orientations as well as the social consciousness and values of young persons (aged 15 to 29 years) living in the greater Tokyo metropolitan area. The study was first conducted in 1976 and continued at 3-year intervals. This is absolutely the first continuous research of its kind conducted on youths and is the only investigation that compares 1) the effects of social shifts on trends in the young with 2) stages that occur as one passes from adolescence to adulthood.

The values and activities of youngsters vary even if they live in the same city like Tokyo. This study classified the youngsters into four types according to their values and observed the shift of types with the passage of time (which type increases and which type decreases).

"Steadily achieving" (reliable, consistent)

This type embraces the social norms maintained by adults up to the present. They are willing to tolerate and preserve in the face of severe hardship.

"Non-confrontational" (peaceful)

They show little consideration for theory or ideology, displaying the most interest in matters directly involving themselves. They believe that what happens in the world around them holds no concern for them personally. They are realists, immersed in the here and now, expressing little concern for the future.

"Malcontent" (disgruntled and intolerant)

They are a sullen bunch, and see every aspect of the world as having cause for complaint. Nevertheless, they are unable to answer when asked what troubles them. They demonstrate great distrust of others and are rebellious when pushed or lectured.

"Autonomous" (independent and composed)

Members of this group move at their own steady but leisurely pace, first reading a situation carefully, and then responding to the circumstances as appropriate using their own judgement. They are skeptical towards values upheld by adults. They are insistent upon their own sense of values. They have a strong sense of justice, yet being logical and methodical, they do not act rashly. They are an intellectual group.

During these 20 years since the study was started, the number of youths, both males and females, of "steadily achieving" type and "autonomous" type has decreased and the number of youths of "non-confrontational" type and "malcontent" type has increased. However, since the bubble period, changes show a tendency to become more moderate and/or return back to previous states. This trend may be a result of the more severe social environment after the bubble burst.

Considered in conjunction with results of other questionnaires issued in this study, in general, images of Japanese youths in this modern age can be summarized as follows:

(1) Increasing distrust of adults: Dissatisfaction with the present state of society (current state of politics and social systems) as well as a strong mistrust of adult members - increasing rebelliousness against the values and lifestyles espoused by adults.
(2) Increasingly 'self-oriented': Although rebellious, Japanese youths display no intention or will to devote effort to revolting against adults and reforming society. In addition, they display no intention to work together in generating a new sense of values or lifestyle shared by all members of their age group.
(3) Insisting on their own senses of value: They acknowledge that they live in an era of material prosperity and continue to enjoy the blessings of their fortunate situation. Given that they live in prosperous surroundings, they state a desire to create and bury themselves in an environment of setting surrounding by only that which appeals to them and where they can feel satisfied.

They tend to separate from the world of adults and move towards a "world of their own". For adults, they are becoming strangers living in a "different world".

There are advantages and disadvantages in such a trend for Japanese youths.

Advantages: They have the potential to diverge from the group oriented behavior or uniform consciousness traditionally favored and adhered to by the Japanese. As a result, for instance, there is a possibility of starting new industries such as fashion and games.

Disadvantages: There is a risk that the majority of people will not be interested in others and the society and sink into a self-satisfied, complacent world.

What we have to do as adults is to foster many "autonomous" type youths because they will create their own new values that replace adults' values or lifestyles and implement their way of living based on their values.

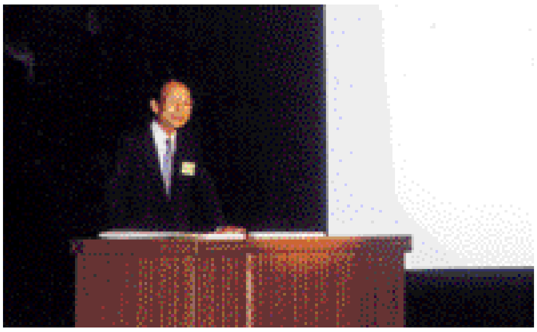
(As an answer to a question): These youngsters will be interested in micromachines. I expect development of micromachines that do not cut off face-to-face human relationships.

(This manuscript is a summary by the administration of the lecture and manuscript by Professor Kadowaki.)

Science Museum: Micromachine for Use in an Educational Exhibition

Tatsuo Hayashi
Director, Japan Science Foundation

The Science Museum has demonstrated and exhibited three types of micromachines that were developed by supporting members since this April. Mr. Tatsuo Hayashi, Director of the Japan Science Foundation presented a speech on the significance of micromachines as exhibits, effective ways of showing them to young people, and responses from young people through their experiences.



Outline of the lecture

The Science Museum exhibits a range of activities which teach young people the pleasure and fascination to be found in the appreciation of science and industrial technology. The Science Museum helps visitors to enter a world of science and industrial technology, a world so close and yet still undiscovered.

The method is to give visitors the opportunity to experience for themselves the joy of hands-on discovery.

The micromachines (referred to as MMs henceforth) were exhibited based on the following three concepts:

(1) Helping to develop curiosity about the unknown world
(2) Giving ideas for the future technology of Japan
(3) Showing importance of supporting technology

Practically, the following three MMs were exhibited, enabling visitors to observe how they move.

- <u>Ladybird type actuator using microphotoeletric device converter technology:</u> A ladybird type actuator (1cm ¥ 1.5cm) moves autonomously within a light spot that can be moved freely.
- <u>Micro testing machine inside tubing using a flexible piezoelectric actuator:</u> The structure allows detection of abnormalities in the transparent narrow tubing through to-and-fro movement inside the tubing by external control. (Diameter 5.5mm, total length 20mm)
- <u>Micro-manipulator using shape memory alloy actuator technology:</u> The structure operates the micro-manipulator (diameter 1mm, total length 80mm, degrees of freedom 5) to strike a small piano keyboard.

One instructor is assigned constantly to the exhibition to provide operation instructions and introduction of details through a CCD camera, video, and panel.

To enhance the effects of the exhibition, questionnaires were filled out by visitors. The contents of the questions and answer status are described below.

Q1: Did you know about MM?
Approximately 50% knew about MM. (This figure was approximately equal for both adults and elementary/middle-school children.)

Q2: What did you think of the MM exhibition?
All the young people rated it as interesting. For adults, the figure was 60%.

Q3: Which part interested you?
The aspects cited as most interesting were 'small size' and 'precision of movement'. The excellence of MM technology was described as 'Wonderful!', indicating that visitors derived pleasure from the exhibits at a sensual level.

Q4: Is there anything you would like to know more about?
Things they wanted to know:
The elementary school children were most interested in the movement mechanism, while the middle-school and older children were also interested in the way it will be used.

From the above, the following may be said about this exhibition:

(1) Almost everyone found the MM exhibition "interesting" or "very interesting". In particular, visitors were able to understand the incredibly advanced and complex world of scientific and industrial technology behind this through bodily sensations. This tendency was especially striking in the younger age group.
(2) Things the visitors wanted to know more about included "mechanism" and "method of use." The kind of questions asked is an indication that our attempts at substantially boosting the interest of young people in MM were successful. For ideas in relation to the "method of use", in order to stimulate visitors to think about this, they were invited to enter a painting competition sponsored by MMC.
(3) Since there were many requests to touch the ladybird type actuator exhibition, it is important to prepare a replica which visitors can actually touch. By increasing their familiarity with the technology in this way, the effectiveness of the exhibition will be enhanced.

We would like to develop a more effective exhibition based on the results of this exhibition. MM technology is packed with dreams. We would like to fill the Science Museum with themes with dreams.

(This manuscript is a summary by the administration of the lecture and manuscript by Mr. Hayashi.)

MEMS Education Program at UCLA

Chang-Jin "CJ" KIM
Professor, UCLA

Prof. Kim presented a speech on MEMS education in UCLA, where a formal Ph.D. Major Field in MEMS has been established for systematic education of MEMS.

Outline of the lecture

To begin, I would like to discuss why a special education program is necessary for MEMS. MEMS technology is quite different from conventional engineering. While in conventional fabrication physical processes are mainly implemented in three-dimensional space, in MEMS chemical processes are most common along with two-dimensional lithography. To assemble parts, a technique called pre-assembly is important in MEMS. These differences in manufacturing are relatively well understood.

What are less apparent but perhaps more profound, dealing with MEMS, are the fundamental differences in physics, especially mechanics. For instance, common microbeams in MEMS are on the order of micrometers, the scale that has never been handled as "mechanical" by conventional engineering. Do we, creatures in macro-world, really know how to design mechanical devices, i.e., machines, that need to function in microscopic world? Therefore, concrete understanding and full considerations of scale effects differing from conventional engineering are necessary in designing MEMS. To achieve this, an academic approach is necessary, thereby requiring a special education program.

The MEMS education at UCLA is centered around the graduate program. The purpose of this program is to lead students to comprehend the basic differences between the existing engineering and MEMS. The students are asked to appreciate the world in microscale, to learn all the important microfabrication technologies, and to understand the key transduction principles that relate the micro-world with human.

At UCLA we have been running an ad hoc Ph.D. major field in MEMS between Mechanical and Aerospace Engineering Department and Electrical Engineering Department since 1994. In 1997, UCLA formally approved MEMS as a new Ph.D. major field in the Mechanical and Aerospace Engineering Department.

The current program consists of basic courses called "core" and special courses called "advanced/specialty". The core courses deal with the fundamental knowledge necessary to achieve the goals described above, highlighting the science in microscale and the technologies relevant to MEMS while encompassing various conventional engineering disciplines like materials, mechanics, and electricity. Subsequently, the students proceed with own specialty field, such as fluid mechanics, heat transfer, control and robotics, communications, aviation, optics, biomedical areas, or advanced MEMS.

Each core course is outlined below as well as an exemplary list of specialty courses.

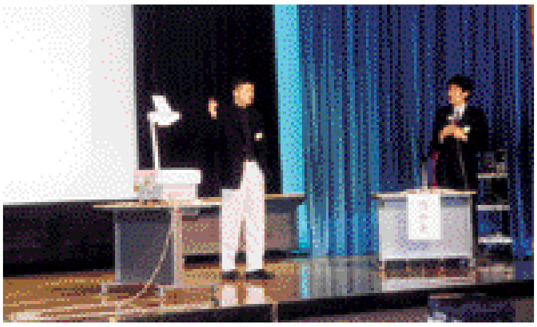
Core

Introduction to Micromachining and MEMS Laboratory

The course is currently the only undergraduate course in the program and provides the essential technical background for lithography-based micromachining. In addition to regular lectures, students acquire hands-on experience with micromachining by fabricating a set of basic MEMS elements through the 10-weeks course in a 1,000 square-foot clean room dedicated for education.

MEMS Fabrication

The course provides the knowledge in MEMS fabrication for advanced research and development of MEMS.



Microsciences

The course challenges the students to understand the phenomena in microscopic world and teaches the topics important for micro-engineering in such fields as basic sciences, fluid mechanics, heat transfer, and tribology.

MEMS Device Physics and Design

The course deals with various transduction principles such as piezoelectric, electromagnetic, and electrostatic and also discusses how MEMS devices are actually designed and produced. This course also teaches design rules and mask layout and introduces some foundry services as well.

Specialty

In addition to the core courses, students take the specialty courses according to their own interests and specialty. The specialty areas can widely differ depending on each individual's background and career goals. Each student selects a series of 2-4 courses formed around the theme. The following set of courses is simply an example.

Sensors, Actuators and Signal Processing

The course teaches microtransducers and signal processing principles.

Experimental Mechanics for MEMS

The course teaches material and mechanical properties, such as strength and fatigue, and the methods to characterize MEMS structures.

Advanced MEMS

The course treats some selected topics in depth and discusses the latest research activities in MEMS field. The course also includes case studies of commercial MEMS product and packaging.

After completing these courses, students take a comprehensive examination consisting of six hours of written and three hours of oral tests. To complete the MEMS Ph.D. program, in addition to passing the comprehensive examination, students must complete 3 courses in each of two minor fields other than MEMS.

Up to the present, more than 20 Ph.D. Students have completed the program, and many more students have obtained M.S. degrees. Currently, there are over 70 students and more than 7 professors in the program.

The field of MEMS is dynamic and progressing rapidly. To accommodate the growth in educational demand as well as the advances in the field, our program is constantly being adjusted and expanded. What has been reported today is simply a snap shot of today. Education is as exciting as doing research in MEMS.

(This manuscript is a summary by the administration of the lecture and manuscript by Professor KIM.)

Exhibition “Micromachine ’99” Held

The 10th Micromachine Exhibition “Micromachine ’99" was held successfully with The 5th International Micromachine Symposium. The three-day exhibition was held from October 27 to 29, at Science Museum, Kitanomaru Park, Tokyo.

Exhibitors were enterprises, non-profit organizations, universities and colleges, and research institutes from Japan and abroad, including Micromachine Center and 22 supporting members of MMC. The member of exhibitions were 86, surpassing previous exhibitions. With the latest micromachine technologies and research results on exhibit, this event is growing year after year both in scale and contents as the biggest exhibition of micromachine technology not only in Japan but in Asia.

This time, the first model systems were collected together and made public and demonstrated for the first time. The systems were the grand results of the research and development for the past nine years from participant enterprises of the Industrial Science and Technology Frontier Program sponsored by MITI “Research and Development of Micromachine Technology” that has been carried out as a 10-year plan.

Businesses involved in micromachine R&D demonstrated their technologies, equipment and products at the exhibition, universities and research institutes announced their research results, and newcomers seized the opportunity to launch their new products and technologies.

Exhibition full of inspectors from Japan and abroad

The exhibition was televised and the micromachine exhibition was televised on the “Super News” by Fuji Television on the evening of October 27 and “World Business Satellite” on Television Tokyo.

Visitors totaled about 3,600 over the three days nevertheless a heavy thunderstorm in the afternoon of the first day. With many sparing much time to observe exhibits and asking questions to the staff, the place was crowded and filled with excitement. The results of the questionnaires given at the end of the exhibition shows high evaluation gained from the exhibitors also and 83% of exhibitors wishes to exhibit next year.

Memoirs

Iwao Fujimasa
Professor, National Graduate Institute for Policy Studies (GRIPS)

It happened in the summer of 1988, which is still vivid in my memory. At the committee sponsored by MITI, I told Naomasa Nakajima, professor of the University of Tokyo, who was sitting next to me, that I was wrestling with the difficulty of miniaturizing an artificial heart for inplanting in the body and that miniature parts would be required in the medical field in the future. He agreed with me on the necessity of miniature mechanical parts in the industrial field as well in the future. At that time, many of the researchers who joined me in the Research Center for Advanced Science and Technology (RCAST) of The University of Tokyo were showing an interest in this subject, and a preliminary meeting was proposed by way of forgetting the summer heat on August 26 when the summer vacation ends. In addition to the above members of the RCAST, Hiroshi Imachi, assistant professor of the medical department, specializing in biomedical materials, Hiroshi Matsumoto, guest professor specializing in tissue engineering, and Eiichi Tamiya, assistant professor specializing in biosensors, also attended the meeting. It was decided then to start up the first society for research in the field of RCAST’s biomedical devices on October 11. In the photograph taken at the first meeting, now on hand, Yasuhiro Shiroki, professor specializing in the manufacture of semiconductor elements, Masao Karube, professor of biosensor division, Kazuhiko Atsumi, professor of the medical department, Hiroyuki Fujita, professor of the Institute of Industrial Science, and professor Yotaro Hatamura and assistant professor Michitaka Hirose of the engineering department, in addition to the above members are lined up. The topic then turned to naming the research society. Finally, the name “Micromachine Research Society” was adopted.

The first micromachine exhibition was held at the Machinery Promotion Hall in Shiba Park, Minato-ku, in March 1990. Thanks to MITI’s decision to start up a micromachine project in the National Research and Development Program along with the co sponsorship of the Japan Industrial Robot Association, the first exhibition was attended by a reasonable number of companies and research institutes.

The second micromachine exhibition was held jointly with MEMS (Miniature Electric Machine System) Workshop, sponsored by IEEE and held for the first time in Japan, at the public hall, Big Roof, in Nara City, on January 30 through February 2, 1991. It was from that year that MESAGO Japan organized and managed subsequent exhibitions. Partly because the micromachine project in the National Research and Development Program was started that year, many participants in line with the efforts of Messrs. Fujita and Esashi, contributed a great deal to creating a magnificent symposium and exhibition. Since the 4th micromachine exhibition held in 1993, the micromachine symposium and exhibition came to be held together at the Scientific Museum in KitanoMaru Park, Tokyo as we see now. Both the micromachine symposium and exhibition were held every spring until 1994 under the sponsorship of the Micromachine Center and the Micromachine Research Society. Since 1995 when the micromachine symposium became the International Micromachine Symposium, the micomachine exhibition has come to be held in October every year up to the present.

The Japanese economy has been depressed for some time during which period the micromachine project has been in progress. Fortunately, however, the micromachine exhibition continued to expand in scale year after year and it has now become the world’s largest micromachine show. As one of the members who planned the exhibition for the first time this gives me great satisfaction. I would like to applaud the participants from the research institutes and companies who have brought the exhibition up to this level and those concerned in the management of the exhibition.

Research on Basic Micromachine Technology for Fiscal Year 1998 (Part II)

Since 1992, the Micromachine Center has taken up a various seeds of technology as themes for joint research by academic, government, and industrial sectors, aiming to reinforce basic technologies by searching for technology seeds, especially in the scientific and technological fields, that are necessary to build various micro systems. In fiscal 1998, research has been carried out on nine themes. Continuing from the last issue, the remaining four themes are summarized below.

Research on Processing, Integration, Connection, and Assembly Techniques for the Realization of High-level Complex Structures

Mikio Horie
Professor, Interdisciplinary Graduate School of Engineering/
Precision and Intelligence Laboratory, Tokyo Institute of Technology

The investigative study group carried out an investigative study of the following four themes under the captioned subject:

1) Investigative study of a micromachine mechanism using large-deflective elastic hinges
2) Investigative study of a microactuator using large-deflective elastic hinges
3) Investigative study of the formation of a three-dimensional structure by anisotropic etching of silicon crystals
4) Investigative study of the manufacture of a three-dimensional micromechanism by bending a plane

The above themes are related to the techniques of processing, integration, connection, and assembly for the realization of characteristic high-level structures, respectively:

1), 2) A technique to enable the elements in the substrate (thin film) to realize movement of more than two dimensions with the actuator in the substrate
3) A technique of forming a thick structure
4) A technique of assembling thin films into a three-dimensional structure

In the “Investigative study of a micromechanism using large-deflective elastic hinges” (by Mikio Horie, Professor of both Interdisciplinary Graduate School of Engineering and Precision and Intelligence Laboratory, Tokyo Institute of Technology), the investigative study of a kinetic three-dimensional structure was carried out, proposing a mechanism composed of large-deflective elastic hinges, with the pair parts in a 2-degree-of-freedom 5-link PRRRP mechanism (P: Prismatic pair; R: Revolute pair) replaced with hinges, on the basis of overall numbers relative to a microsize three-dimensional motion convert mechanism. On the basis of the proposed mechanism, displacement and force characteristics of the microsize mechanism have been clarified theoretically, and then the process of manufacturing a three-dimensional motion convert mechanism with the semiconductor fine processing technique, and the microsize mechanism (a micromechanism) manufactured by the foregoing process are indicated. At the same time, the trends in this field were investigated in the international convention held only recently (KACC’98, Japan-France Mechatronics International Convention 98, SPIE ’98).

In the “Investigative study of a microactuator using a largely deformed elastic hinge” (by Daiki Kamiya, a Research Associate of Precision and Intelligence Laboratory, Tokyo Institute of Technology), the presentation of the process of manufacturing, trial manufacture, and experiment of a metal film-covered plastic comb-drive electrostatic actuator were carried out to clarify the property of driving the comb-drive actuator. This study was conducted in conjunction with a trend investigation (MST-98).

In the “Investigative study of the formation of a three-dimensional structure by the anisotropic etching of silicon crystals” (by Kazuo Sato, Professor of Graduate School of Engineering, Nagoya University), the properties of anisotropic etching of silicon crystals were measured for evaluation under wide-range conditions with the kind, concentration, and temperature of an etching solution preset as parameters, and the new possibility of three-dimensional structure processing of monocrystalline silicon was discussed. A trend investigation was also carried out at the same time (Transducers-97, MEMS-97, Workshop (Physical Chemistry of Wet Chemical Etching of Silicon (1998)), MEMS-98 and MEMS-99)).

In the “Investigative study of the manufacture of a three-dimensional micromechanism by bending a plane” (by Masaharu Takeuchi, Researcher of Shimoyama-Lab.(Mechano-informatics), Graduate School of Engineering, The University of Tokyo), a report was made on the trial of manufacturing a self-assembling three-dimensional structure using the following: the technique of assembling a three-dimensional closed-loop structure as if folding a plain folding paper, the trial utilizing the Lorentz force used for assembly, and the thermal distortion caused by polyimide soldering.

A high-level complex structure should be realized as the means of realizing a micromachine with excellent functions. This will accelerate the compounding of entirely different manufacturing process techniques, such as techniques of compounding a multilayered structure itself, and combining of the thin film technique for the manufacture of extremely small functional elements and high-density electronic circuits and the LIGA process technique suitable for the manufacture of a thick structure.

Research on Functional Systems Utilizing Micronization Effects

Nobuo Ohmae
Professor, Faculty of Engineering,
Kobe University

Microtribology can be considered to end up in so-called atomic manipulation, that is, to manipulate atoms one by one. In fact, the report by Eigler et al. of IBM, lettered atoms under a scanning tunneling microscope came as a major surprise to us. In this analytical study, the author investigated how two physical phenomena are interrelated with the origin of microtribology. The two physical phenomena are 1) a micronization effect, that is, to cut down a solid substance into the smallest possible particles, and 2) a proximity field*, that is, to bring two surfaces as close together as possible.

A giant step can be made toward the solution of the problem of micromachine tribology if the movement of atoms can lead to the transport of a cluster or a slightly larger meso-size object. The author then investigated examples of research on atomic manipulation by scanning probe microscopy (SPM) to study the research direction with which to understand the above mechanism on the basis of those examples. This study revealed that the experiment of atomic manipulation was successful only when STM was used and that, strangely, almost no experiment was successful when the atomic force microscope (AFM) was used except for the handling of superfine particles. One may readily expect that cluster manipulation can be finely achieved if a tip can carry an object atom (or vice versa) after attracting it by intermolecular action. Undoubtedly the difference in principle between STM and AFM lies in a tunneling phenomenon and an interatomic force. Particularly, in the case of STM, an electric field works as a bias between a tip and a sample. Accordingly, the fact that an electric field works may be considered to be a determining factor in atomic manipulation.

The emission of interstitial Si (an electric field of 10^7 V/m), the field emission of electrons ($10^{8\text{-}9}$ V/m), and field evaporation (10^{10} V/m) are well known surface phenomena. As described above, it is highly likely that atomic manipulation is fundamentally the result of a very minute evaporation in an electric field under its influence. In other words, atomic manipulation using the STM is summarized as the following two cases: one is to manipulate substrate atoms or adsorbed atoms by changing the electric field in pulse modulation (sample bias), while the other is to induce interaction by narrowing a spacing between a chip and a sample thus to reduce tunnel resistance (breakdown of substrate atoms or movement of adsorbed atoms). It therefore follows that, since the potential barrier is significantly narrowed when two surfaces are brought closer (to each other) under the influence of the electric field, the tunneling phenomenon of atoms is activated to such an extent that the desorption and recombination between the atoms on top of the surfaces are very likely to occur. Again, when observing the atomic structure of Si under the field ion microscope (FIM), we can see atoms change their positions on the (111)-plane terrace independent of a large-scale field evaporation. Such atom movement accompanies a change in the local electric field, which can be accounted for the surface reconstruction** by adatoms. It appears likely that atoms move frequently under the influence of the electric field.

Based on the analytical findings as described above, it is apparent that the mechanisms of micronization and the proximity field should be analyzed further into the physical properties of electrons on the surface. This prompted the author to carry out computer simulation with a group of programs (BB-BV) for energy optimization relative to the positions of atoms by the band calculation based on plane-wave with an ultrasoft-pseudopotential applied. The findings derived revealed that the local density of states of atoms is present slightly above the Fermi level due to the adsorption of oxygen, point defects, and atomic steps. On the actual surface with the discontinuity of a cluster or a domain structure, a tunnel phenomenon is highly likely to occur from a level close to the vacuum level as described above.

Not only the analysis based on electronic characteristics, but also the study of molecular dynamics is required. Although the study of molecular dynamics was also continued in this investigative study, a guideline has been established that the physical properties of surface electrons should be prescribed beforehand so that a correct potential can be structured. However, by adding a heterogeneous structure to a material and after full metallurgical relaxation, it is estimated from molecular dynamics to be the extent of 10 nm what distance the heterogeneous structure influences on its elastic constant. In other words, unless a material is reduced to below 10 nm, the peculiarity of its surface or interface cannot be recognized. This differs greatly from atomic manipulation, suggesting the necessity of constructing the above-described physical model.

* The concept of a proximity field is based on the terminology by Naotake Ohyama, Mechanical Engineering Laboratory.

** Research findings unpublished.

Investigative Study of Stimulus-response Functions of Organisms and their Application to Micromachines

Ryohei Kanzaki
Associate Professor, Institute of Biological Sciences, University of Tsukuba

Plants do not appear to move. In some cases, however, their movement against various external stimuli is so distinctive that it can be observed with the naked eye. A mimosa and an insectivorous plant move as fast as contractions of the skeletal muscle system. However, the mechanisms of the movement of the former is based on physical turgor pressure, a movement mechanism entirely different from that of the skeletal muscle system which uses contractive protein. This is called a Nastic Reaction, indicating that a plant moves reactively independent of the direction of external stimuli. On the other hand, plants also show a tropism constantly related to the source of stimulation, for example, by growing toward a brighter direction in search of the sunlight or curving upward on toppling sideways by sensing gravity. This tropism stems from a difference in the partial growth capacity of plants.

A plant moves not only macroscopically as described above, but also microscopically on a cell level. Protoplasmic streaming is one of the intercelluar organella, and is indispensable to the transport of material. This flow is caused by the actin-myosin system as in muscles. In addition, plants breathe through minute openings on their leaves, called stoma. The stoma open and close in response to the external environment, with this controlled by the turgor-pressure movement of the cells around it.

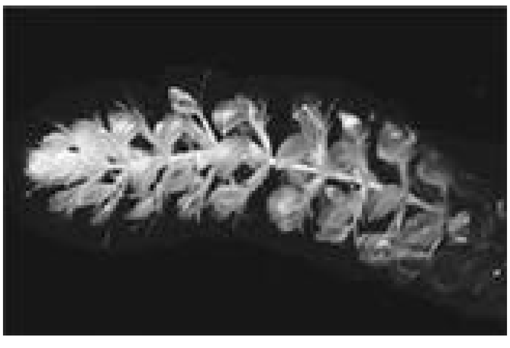
In this investigative study, emphasis was placed on the macro- and micro-scopic movements of a plant in response to changes in the external environment, including (1) a protoplasmic streaming, (2) a nastic reaction (turgor-pressure and growth movements), (3) the opening and closing of a stoma, and (4) a tropism.

The mechanisms of generating a force by the actin-myosin system, a minute system contributing to the protoplasmic streaming, is basically the same as that by the actin-myosin system involved in muscle contraction. However, a change in part of the functions of myosin molecules has led to a difference in the intercellular structure. This resulted in a protoplasmic streaming and muscle contraction, movements that are entirely different from each other. It appears that in the initial stage of evolution they had similar functions, but that in the process of evolution, they acquired functions suitable for their respective living forms. In animals, calcium activates the actin-myosin system, whereas, in plants, it retards protoplasmic streaming. This may be a result of the same causes. The myosin involved in the protoplasmic streaming of chara has been found to move much faster than the myosins of all animals and plants, a characteristic phenomenon that should not be overlooked when applying the mechanisms of sliding of the actin-myosin system to micromachines.

Protoplasmic streaming is caused principally by two functional elements, actin and myosin. On the other hand, however, a nastic property, stoma opening, and a tropism can be realized only when many proteins work cooperatively as functional elements.

Turgor pressure is generated by the presence of cell walls, one of the phenomena peculiar to plants. The turgor pressure is important for plant cells for maintaining their forms and for growth. A reduction in turgor pressure in part of the tissue cells not only results in plant movement but also in stoma opening. For example, a mimosa moves as fast as skeletal muscles. In both cases, however, their movement is based on different respective mechanisms of force generation.

Recent studies in the field of membrane biology are revealing that many transport molecules are common to animals and plants. It will be a major future task to clarify what kind of network these molecules actually form, and, in addition, how minute structures composed of protein are related with each other for the setting up of the stimulus-response system of a plant.



A catchfly (top) and aldrovanda (bottom). Both of them have similar insect-catching leaves.

Investigative Study of the Miniaturization of Chemical and Biochemical Analyses/Synthetic Systems and Physicochemical Reaction Systems

Shuichi Shoji
Professor, School of Science and Engineering,
Waseda University

In the investigative study carried out last year concerning chemical analysis and sensor technologies (μTAS), the author investigated the trends of miniaturization of a chemical analysis system. The research in this field is increasingly expanding, particularly in Europe and the U.S., with over 150 research works published in the 3rd Micro Total Analysis System Workshop, held in October, 1998 in Banff, Canada, in which there were 400 participants, double the number at the previous meeting. Furthermore, the number of research works published is also increasing in micromachine-related international conferences and meetings. This induces us to believe that the research toward the commercialization of μTAS is progressing at a faster rate.

μTAS can broadly be divided into two categories: one is so-called MEMS (Micro Electro-Mechanical Systems) with a mechanical fluid control mechanism, as in micropumps and microvalves, the research on which has been carried out principally in Europe, while the other is of a chip capillary electrophoresis type, utilizing a non-mechanical fluid control mechanism based on electroendosmosis, chiefly being developed in Canada and the U.S. Both of them belong to a flow type system in which a series of operations consisting of mixing/reaction-separation, and detection is carried out continuously in a microchannel. On the other hand, another branch of research on a batch-type system is also under way, in which a series of reactions and analyses is carried out in micro chambers formed in a matrix state by micromachine technology.

This time, the author investigated the progress of chemical and biochemical analysis with emphasis placed on the theses published in related international conferences and meetings held in 1998. The examples reported to date were also investigated in terms of chemical and biochemical syntheses and physicochemical reactions. First, microfluidics and its applied devices were described as important system elements, along with the technique of fabricating a microsystem in terms of the application of the micromachine technologies. Next, the application to the bio field and examples of the application to chemical and biochemical synthetic reactions were introduced. In addition, the microphysicochemical reaction system reported recently was described.

As the research on microfluidics is indispensable to the development of a flow-type system, it is being carried out continuously. In this research, the micro capillary electrophoresis chip research that takes advantage of electrokinetic phenomena, including electrophoresis and electroendosmosis is conducted extensively, in line with the development of the CAD for microfluidic analysis as a design-aid tool. The research on the conventional mechanical microvalves and micropumps is focused on commercialization. However, a new trial on flow control compatible with the miniaturized system is also reported. A technology of fabricating a microsystem is under investigation with the method of fabricating a microchannel as the main focus of the research, along with propositions on the respective methods of fabricating silicon, glass, plastic, and metal materials. Various techniques of manufacturing the systems for every element is also under development. As one of the current trends, the number of reports on the fabrication of plastic elements by injection molding for cost reduction is increasing, indicating a transition to commercially conscious research. The research on an analytical system in Canada and the U.S. is clearly purpose-oriented. The research focused on the application to biochemical research mainly around DNA analysis, is actively in progress, particularly in the fields related to the full-fledged applications of capillary electrophoretic chips and DNA chips. An optical method using fluorescence is principally used for detection. Recently, biomolecules, larger in molecular weight, have come to be bioassayed, including enzymes, proteomes, antigens, and antibodies, accompanied by an increase in the number of high-resolution mass spectrometers used as detectors.

Also expanding is the research on miniaturization of reactors for chemical and biochemical reactions. According to reports, biochemical synthetic systems are available: one for the synthesis of DNA as in PCR, and the other for the biochemical reaction of polymers, such as proteins. A batch-type system with micro reactors arrayed and a flow-type system utilizing a continuous flow in a microchannel have been developed, both of which are aiming at realizing the improvement of efficiency in synthetic reaction. Only a few examples of microsystems for physicochemical reactions are available. However, the microsystems have succeeded in precise reaction control by integrating the sensors of flow, temperature, etc. as well as by miniaturizing a reactor. One of their merits is particularly noteworthy in that miniaturization has enabled reactions accompanied by a sudden change in volume to be carried out in complete safety, particularly reactions which carry the risk of explosion. The research theses published in Japan are fewer than those in Europe and the U.S. However, in view of the widening interest by those concerned in this field, we can expect fruitful research to be produced by utilizing the high technological capabilities of this country.

Yaskawa Electric Corp.

Tadashi Sumimoto
Director
Basic Research Laboratories

1. Tackling Micromachine Technology

In modern life, we are surrounded by many high-tech items, including automobiles, computers, and cellular phones. Japan is distinguished in mass-producing those items and distributing them throughout the world. This is supported by the concept of mechatronics, a fusion of machinery with electronics. This concept was proposed by the company in 1969, and remained registered as the company's trademark until 1982. A robot is representative of the company's products. However, the company continued to experiment with a "Super-mechatronics" project that evolved from this concept until it succeeded in developing a vacuum robot in 1987, the first such product in the world. It is producing items related to semiconductor manufacturing devices, such as a clean vacuum robot and a composite carrier system. A servo actuator adopts the role of the heart for these devices. We are being confronted with various issues, from preventing environmental pollution, securing energy resources, and coping with a highly advanced information society. However, the writer is confident that the micromachine technology will serve as a breakthrough in solving these problems. The company is also hoping to contribute to solving those problems by positively developing micro-servo-actuators and systematization techniques.

2. Development of Micromachine Technology

In the "Micromachine Technology Research and Development" Project, the company is taking part in the research and development of a desktop-size "microfactory" that integrates devices for carrying out many processes, including processing, handing, assembly, and inspection. In the research and development of its systemization technology, the company is developing an inspection unit and an assembly stage for observing and inspecting the states of processing and assembling microparts, such as a gear train, and a micro-servo-actuator that drives the aforementioned devices.

An actuator is required to transfer an environment-recognition device and a rotary table at speed to a preset position and position them with a high degree of precision. This necessitates not only a small size and a high torque, but also a servo function to enable high-precision positioning and high-speed control. At present, AC servo actuators, 5 mm and 10 mm in outside diameter, the smallest in the world, are under development. In addition, an inspection unit and an assembly stage were mounted on the first prototype of the microfactory to carry out functional evaluation. It was thereby confirmed that the inspection unit enabled a full inspection picture to be obtained with a positioning resolution of below 2 μm and that the assembly unit enabled high-precision positioning with a resolution of less than 0.09º and constant-speed rotation. In fiscal 2000, the last fiscal year of this project, the company plans to enhance the performance of the micro-servo-actuator by optimizing a motor structure, improving the resolution of a servo sensor, and optimizing a control alogorithm as well as miniaturizing and improving the efficiency of an inspection unit and an assembly stage.

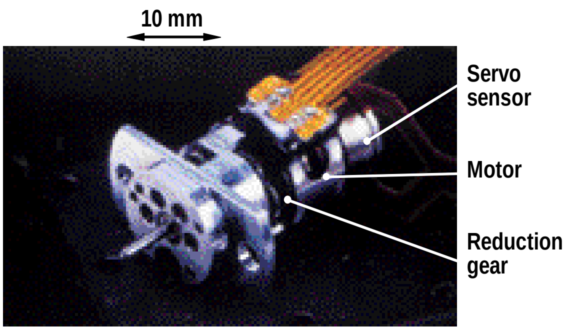


Fig. 1 Micro-servo-actuator

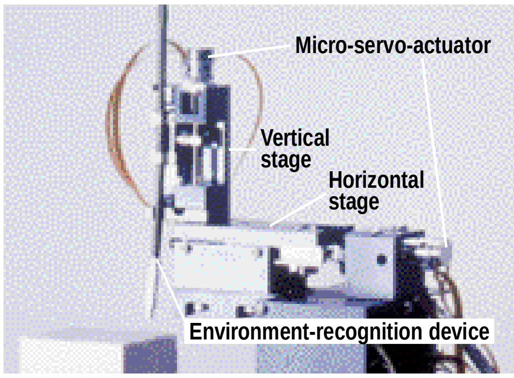


Fig. 2 Inspection unit, developed in conjunction with Mitsubishi Cable Industries, Ltd.

3. Future plans

The super-micro-actuator developed in this project is equipped with the servo function for controlling speed and positioning freely. Accordingly, it is expected to contribute to miniaturizing and rendering intelligent the existing products, such as FA, OA, and information devices and medical equipment, as well as to expand its applications over a wide range as a key device in a micromachine manufacturing equipment system. In the future, the company will try to realize a micro-servo-actuator, to make it more efficient, more reliable, and cheaper.

Yokogawa Electric Corporation

Mamoru Sanagi
Senior Vice President, General Manager of Corporation Technology Development and General Manager of Corporate R&D Center

1. Tackling Micromachine Technology

As technology undergoes drastic changes in response to social needs the company has so far promoted the qualitative evolution of its technological field comprising "measurement, control, and information". With the advance in information and communication technology, society is oriented toward constructing a network as a core basis of the social system. The company is going ahead with the project of technology development with "Field contents on the web", a new technology that enables real-time valuable information to be offered via a network, as a new technological concept.

The company is carrying out the research, development and commercialization of micromachine technology as an elemental technology of "Field contents on the web" alongside the above policy.

2. Development of Micromachine Technology

In the Industrial Science and Technology Frontier Program, the research and development of the following instrumentation technologies is under way as common basic technologies required for realizing micromachines.

2.1 Development of Shape and Size Measuring Technology

The shape and size measuring technology enables the elimination of the influences of fading and scattered light on the basis of the principle of a confocal microscope, so that non-contact high-speed, high-precision measurement can be made of three-dimensional shapes or high-speed motions of micromachines or important parts. It aims at responding to the needs of research and development, and evaluation and standardization of parts. High speed has been achieved by using multibeams for (Nipkow disk) of a confocal microscope. In addition, an optical unit, with a wide field of vision, provided with a large numerical aperture, has been developed by enlarging and optimizing lenses and the light-receiving part. A technology has also been developed which measures a three-dimensional shape and size with a measuring time of 1 msec/picture and a measuring range of 10 mm.

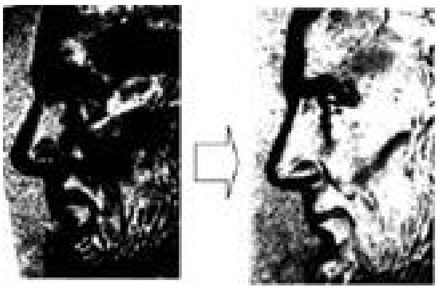


Fig. 1 Relief images of a coin with a conventional microscope (left) and the developed wide field of vision (right)

2.2 Development of force/torque measuring technology

A technology has been developed which measures a micro actuator-produced force/torque of below 1 mN, which cannot be measured by any commercially available devices, a technology realized by applying the company's semiconductor sensor/MEMS technology to a sensor probe. This technology is based on a principle in which a force or a torque for measurement is converted to a strain resistance formed on the beam of a sensor probe with a tip diameter of 10 μm. A minute and local force/torque can be measured over a wide range of 1 μm and dynamic range of 1000.

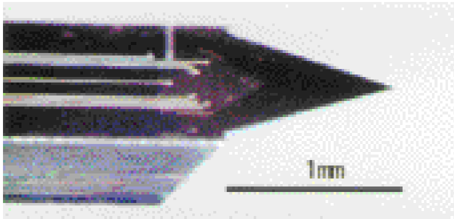


Fig. 2 Micro force probe

2.3 Development of micro-infrared-analyzer

A micro-infrared-analyzer is under development that is to be applied to the detection of inner-tube foreign matter. This analyzer, of less than 1 cm^3 in volume, requires no cooling mechanism. An enlarged model was manufactured on a trial basis, equipped with a wavelength filter with no movable parts, in which transmitting wavelength characteristics differ according to the position, an IR detection element made of micro-processed silicon, and an IR source. This prototype demonstrated that the density of standard CO_2 gas can be measured with a resolution of 100 ppm when a light pass is 45 mm long. It is very likely that a target size of below 1 cm^3 in inner-tube analysis can be achieved.

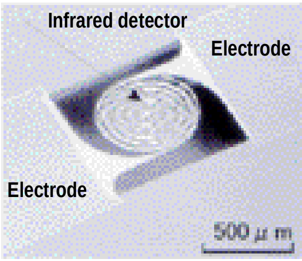


Fig. 3 Silicon infrared detector

3. Future Plans

In the midst of the situation in which society and technologies are rapidly changing toward the 21st century, the company will proceed with the development and commercialization of micromachine technology giving priority to the development of the technologies necessary for differentiation of its business after ascertaining its marching direction.

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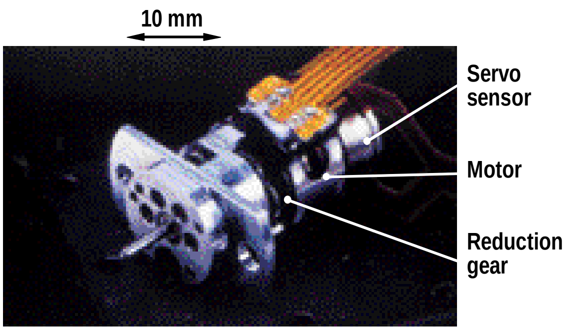

Fig. 1 Micro-servo-actuator

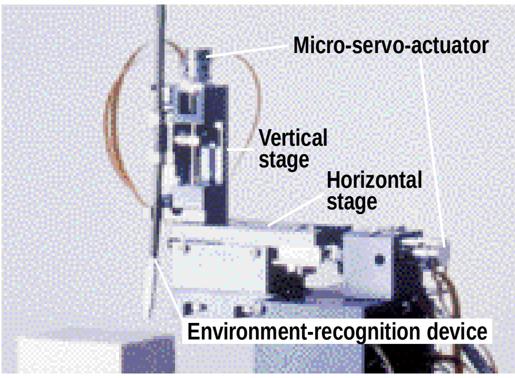

Fig. 2 Inspection unit, developed in conjunction with Mitsubishi Cable Industries, Ltd.

3. Future plans

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As technology undergoes drastic changes in response to social needs the company has so far promoted the qualitative evolution of its technological field comprising "measurement, control, and information". With the advance in information and communication technology, society is oriented toward constructing a network as a core basis of the social system. The company is going ahead with the project of technology development with "Field contents on the web", a new technology that enables real-time valuable information to be offered via a network, as a new technological concept.

The company is carrying out the research, development and commercialization of micromachine technology as an elemental technology of "Field contents on the web" alongside the above policy.

2. Development of Micromachine Technology

In the Industrial Science and Technology Frontier Program, the research and development of the following instrumentation technologies is under way as common basic technologies required for realizing micromachines.

2.1 Development of Shape and Size Measuring Technology

The shape and size measuring technology enables the elimination of the influences of fading and scattered light on the basis of the principle of a confocal microscope, so that non-contact high-speed, high-precision measurement can be made of three-dimensional shapes or high-speed motions of micromachines or important parts. It aims at responding to the needs of research and development, and evaluation and standardization of parts. High speed has been achieved by using multibeams for (Nipkow disk) of a confocal microscope. In addition, an optical unit, with a wide field of vision, provided with a large numerical aperture, has been developed by enlarging and optimizing lenses and the light-receiving part. A technology has also been developed which measures a three-dimensional shape and size with a measuring time of 1 msec/picture and a measuring range of 10 mm.

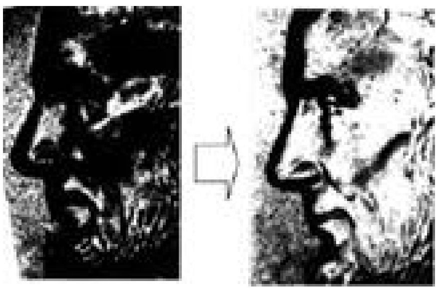


Fig. 1 Relief images of a coin with a conventional microscope (left) and the developed wide field of vision (right)

2.2 Development of force/torque measuring technology

A technology has been developed which measures a micro actuator-produced force/torque of below 1 mN, which cannot be measured by any commercially available devices, a technology realized by applying the company's semiconductor sensor/MEMS technology to a sensor probe. This technology is based on a principle in which a force or a torque for measurement is converted to a strain resistance formed on the beam of a sensor probe with a tip diameter of 10 μm. A minute and local force/torque can be measured over a wide range of 1 μm and dynamic range of 1000.

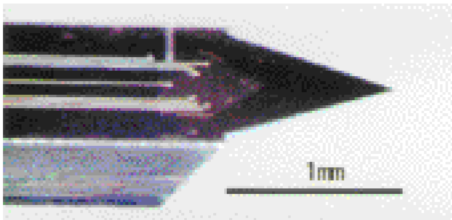


Fig. 2 Micro force probe

2.3 Development of micro-infrared-analyzer

A micro-infrared-analyzer is under development that is to be applied to the detection of inner-tube foreign matter. This analyzer, of less than 1 cm^3 in volume, requires no cooling mechanism. An enlarged model was manufactured on a trial basis, equipped with a wavelength filter with no movable parts, in which transmitting wavelength characteristics differ according to the position, an IR detection element made of microprocessed silicon, and an IR source. This prototype demonstrated that the density of standard CO_2 gas can be measured with a resolution of 100 ppm when a light pass is 45 mm long. It is very likely that a target size of below 1 cm^3 in inner-tube analysis can be achieved.

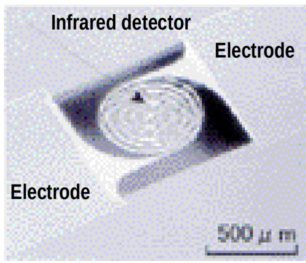


Fig. 3 Silicon infrared detector

3. Future Plans

In the midst of the situation in which society and technologies are rapidly changing toward the 21st century, the company will proceed with the development and commercialization of micromachine technology giving priority to the development of the technologies necessary for differentiation of its business after ascertaining its marching direction.

Report on the Application of Micromachine Technology Overseas

To investigate how micromachine technology is applied in Europe, three persons: Tadashi Hattori, general manager, and Yuji Iwata, manager, of the Information Department of MMC, and Jun Shinohara, Seiko Instruments Inc., visited the following places between September 26 and October 2.

1) Twente Micro Products, University of Twente MESA - Enschede, The Netherlands
2) Ecole Polytechnique Federale Lausanne (EPFL) and Medtronic Europe S.A. (in the suburbs of Lausanne) - Lausanne, Switzerland
3) Micro Engineering 99 - Stuttgart, Germany

Dr. Job Elders, a committee member of SEMI and president of Twente Micro Products, whom we visited first, is greatly concerned about the road map and its economic effects. It was therefore possible to have a significant exchange of views. This company is a venture business established in 1995 with the support of MESA at Twente University, and actively involved mostly in the commercialization of MESA-developed techniques along with the development of MST sensors in collaboration with Phillips.

Next we visited Professor Albert van den Berg at the University of Twente MESA, who explained to us the R & D being conducted by MEMS and MST, that is now under way at MESA. He specializes in TAS, on which subject, he says, a international conference is to be held at his university in May 2000. MESA, with an experiment area for enterprises provided in the vicinity, is jointly tackling R & D with the enterprises with a strong intention of industrialization.

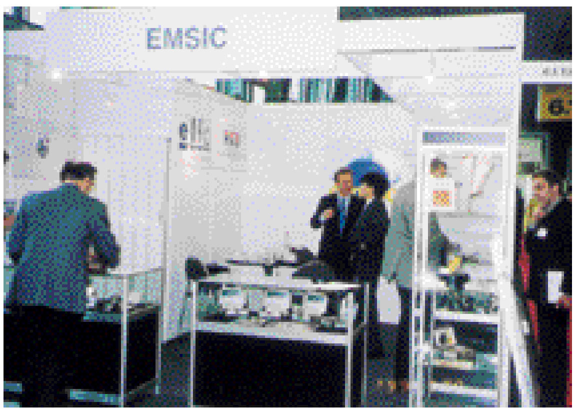
We visited Professor Hannes Bleuler at Ecole Polytechnique Federate Lousanne (EPFL), and were shown into a three-layer structured clean room for MEMS which came into operation this year. We were also given an explanation of the research of the magnetic bearings for HDD - Prof. Bleuler's theme - and the simulator of intra-abdominal surgery by his assistant in charge. According to him, about 40% of the university's research budget is collected from joint research or R & D projects with external organizations, and some 30 companies are cooperating with the university's micro-engineering in order to boost R & D in this field.

At Medtronics Europe S.A., Mr. Dominique Glauser, in charge of the Manufacturing Department, showed us around his factory. This company is a medical equipment manufacturer with its head office and research institute in Minneapolis, U.S.A. Its factory in the suburbs of Lausanne, which we visited this time, is manufacturing pacemakers, accounting for 56% of the world market. This pacemaker is priced at 2,000 ~ 5,000 DM, and lasts for 5 to 10 years depending on the capacity of its battery. Because it is buried in the body, strict quality controls are applied to its manufacture. Its assembly process is not automated, with most of the processes being carried out manually. Since a battery occupies half the pacemaker, its miniaturization and performance improvement will become vital in the future.

Lastly, we attended the exhibition of Micro Engineering 99 held at Messe Stuttgart International, with most of the exhibits from German venture businesses, numbering about 40 in total. We were initially attracted by a venture business established by IMM Research Institute, LIGA gears, mini-motors, mini-sensors and so on.

On display were a laser microscope with a large depth of focus, a gas flow sensor driven by heat flow, a piezoelectric micro-valve, a micro-reactor, a micromotor, and processing techniques. The people in charge of the development of those devices were seen earnestly exchanging views with attendants.

At Prof. Bleuler's room in EPFL



ME99 site scene

Micromachine Seminar in USA

On November 12 (Friday), 1999, a seminar, "Micromachines and Microtechnology; Bio-medical and Industrial Prospects", was held in Cleveland, USA. Micromachine Center has held overseas seminars mainly in Europe to provide information from Japan, collect overseas information, and exchange information. This was the first seminar to be held in the USA. The seminar was planned and implemented with two major themes, biomedical and industrial applications, under the joint auspices of the Micromachine Center, Japan External Trade Organization (JETRO) Chicago Office, and Case Western Reserve University. The speakers and themes are described below.

"The Future Prospects of Micromachines"
T. Hirano, Micromachine Center
"MEMS Activities in the Midwest Region"
M. Mehregany, Case Western Reserve Univ.
"The Microfactory"
T. Ataka, Seiko Instruments
"In-Pipe Wireless Microbots"
N. Kawahara, DENSO CORP.
"Multiple Distributed Micromachine System" M. Takeda, Mitsubishi Electric Corp.
"Laser Micro Processing for Micro Photovoltaic Devices and Systems"
T. Sakakibara, Sanyo Electric Co., Ltd.
"Medical Applications of Micromachines"
H. Mizuno, Olympus Optical Co., Ltd.
"Bio MEMS Electrochemical Immunoassay"
W. R. Heineman, University of Cincinnati
"Micro Technology for MIS [Minimal Invasive Surgery] Devices"
T. Kudoh, Terumo Corp.
"Silicon Based Chemical Sensing Micro Systems"
E. Zdankiewicz, Micromechanical Systems Inc.
"New Transducer for Ultrasonic Diagnosis Using X-Ray-Deep Lithography"
Y. Hirata, Sumitomo Electric Industries
"MEMS and Wireless Communications"
D. Young, Case Western Reserve University

The seminar was very successful, receiving about 90 participants from around Ohio. The results of the questionnaires regarding evaluation on the seminar show high evaluation of follows; excellent:47.5%, very good: 48.8%. In particular, the presentation of the actual result of the ISTF Program provided by the Japan side attracted much interest.

Before the seminar, we visited related research organizations in the USA and Canada for exchange of information and industry exchange. The organizations that were visited and the outline are described below.

(1)Alberta Microelectronic Corporation
Edmonton, Canada, November 8 (Monday)
This company became independent from the Alberta University and is actively promoting commercialization of μ fluidics devices.

(2)Laboratories of National Research Council
Ottawa, Canada, November 10 (Wednesday)
This is a national research organization in Canada. There were also many participants from companies.
In both Alberta and Ottawa, officers of the state and Canadian governments participated, showing strong intentions to commercialize applications in μ fluidics and communication.

(3)Cleveland Clinic Foundation
Cleveland, November 11 (Thursday)
This top-class hospital in the USA is engaged in the latest research and clinical medicine. We received explanations of artificial heart and ultrasound vascular endoscope. It gave us an impression of a perfectly organized cooperative system between the medical and the technical systems.

In this visit, we had a strong impression of how enthusiastically both USA and Canada are tackling application of MEMS technology to telecommunications and μ fluidics for biomedical uses.

Seminar in Cleveland

Recent technological developments – micro-machine-related patent classification has been released

Takayuki Kanzaki
Patent Examiner, Production Machinery Division,
The Third Examination Department, Japanese Patent Office,
Ministry of International Trade and Industry

1. New Institution of Micromachine-related Patent Classification

It has been decided that, on and after January 1, 2000, the micromachine-related classification, "Micro-Structural Technology; Nanotechnology" is to be newly instituted in the international patent classification (IPC), and applied to the countries concerned, including the U.S. and Europe. To cope with this situation, the Patent Office has started using this micromachine-related classification for the classification of Japan's laid open patents and patented inventions. The production machinery division will be responsible for the examination of this classification hereafter.

It has at long last been decided that this classification be carried into effect, after a series of active discussions by a working group consisting of patent specialists in respective countries around the world, mainly the U.S. and Europe, in the World Intellectual Property Organization (WIPO), which have been taking place since around 1996.

2. Summary of Micromachine-related Patent Classification

Micromachines are defined in this classification as machines whose technical characteristics can be observed only under optical microscopes or whose characteristic size is in the order of submillimeters to submicrons. Furthermore, the structure on an atomic/molecular level is specifically distinguished from other micromachine technologies as a nanotechnology. Since it is essential for micromachine-related inventions to prove that the micromachines in question can be manufactured, micromachines and their manufacturing methods are classified in parallel.

Shown in the diagram below is the relationship between the principal and related technologies in the micromachine-related classification. Four English numerals indicate the international patent classification (IPC). [Refer to Examples of micromachine-related technology with patent classification.]

3. Trends in Applications According to Micromachine-related Patent Classification

The Patent Office reviewed the trends in applications by adding the micromachine classification to the following:

Micromachine-related applications (slightly more than 200 cases) obtained independently by the examiners to date in respective technical fields

Applications (slightly more than 500 cases) related to the Industrial Science and Technology Frontier Program "Research and Development of Mciromachine Technology (so-called Micromachine Project)", resulting from the cooperation of the Micromachine Center. The white "Unpublished" section is now being analyzed in preparation for the publication (or withdrawal) of application. [Refer to Recent development of micromachine-related technology.]

Since around 1993, the number of applications has rapidly begun increasing, with applications for around 100 cases being submitted annually at this time. It is expected that, after the completion of the Micromachine Project, the number of micromachine-related applications will further increase based on the results of said project. Application trends will be further elucidated as the operation of the micromachine classification proceeds.

4. How the Patent Office tackles this problem in the future

The Patent Office has just started exchanging views with the examiners in European Patent Office (EPO) so that the information in the U.S. and Europe can be collected, grasped, and utilized for patent examination from an international standpoint. The Patent Office is hoping to work in such manner that will support Japan in becoming a technical leader of the world in the 21st century.

Whom to contact regarding the micromachine classification:

Person in charge of Micromachine Classification,
Production machinery division, the third examination department, Japanese Patent Office,
Tel: 03-3581-1101, ext.3364
Fax: 03-3501-0530

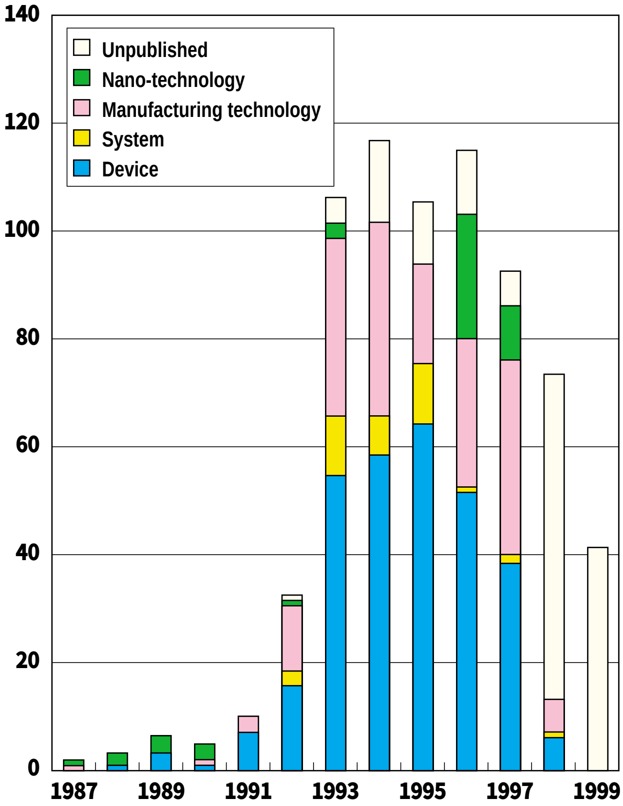
Example of retrieving patent information system (Refer to the following sites for details):

IPDL (Industrial Property Digital Library);
http://www.jpo-miti.go.jp/indexj.htm
PATOLIS (Patent On-line Information System);
http://www.japio.or.jp/japio.htm

(Reference: Micromachine Classification)
MICRO-STRUCTURAL TECHNOLOGY; NANO-TECHNOLOGY

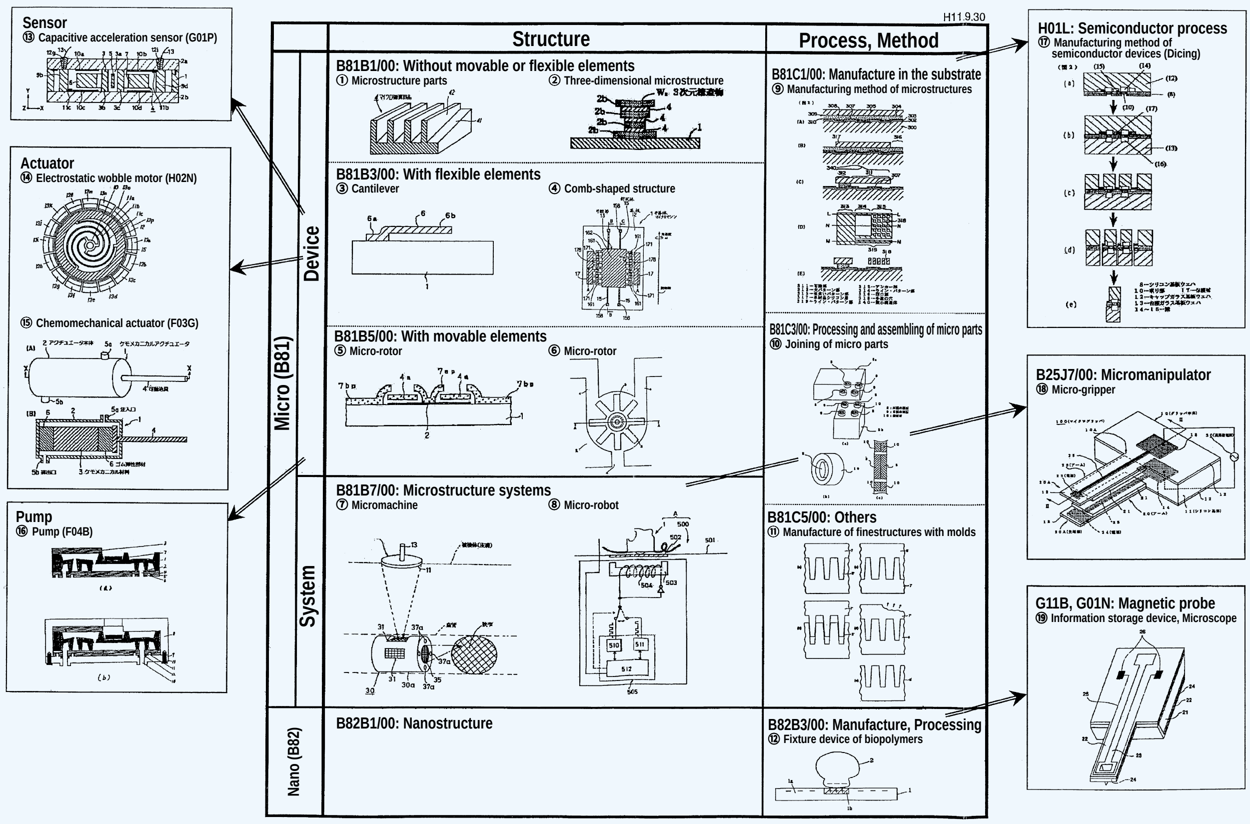
B81:	MICRO-STRUCTURAL TECHNOLOGY
B81B:	MICRO-STRUCTURAL DEVICE OR SYSTEMS, e.g. MICRO-MECHANICAL DEVICES

B81B 1/00: Devices without movable or flexible elements, e.g. micro-capillary device
B81B 3/00: Devices comprising flexible or deformable elements, e.g. comprising elastic tongues or membranes
B81B 5/00: Devices comprising elements which are movable in relation to each other, e.g. comprising slidable or rotatable elements
B81B 7/00: Micro-structural systems
B81B 7/02: • containing distinct electrical or optical devices of particular relevance for their function, e.g. micro-electro-mechanical systems (MEMS)
B81B 7/04: • Networks or arrays of similar micro-structural devices
B81C: PROCESSES OR APPARATUS SPECIALLY ADAPTED FOR THE MANUFACTURE OR TREATMENT OF MICRO-STRUCTURAL DEVICES OR SYSTEMS
B81C 1/00: Manufacture or treatment of devices or systems in or on a substrate
B81C 3/00: Assembling of devices or systems from individually processed components
B81C 5/00: Processes or apparatus not provided for in groups 1/00 or 3/00
B82: NANO-TECHNOLOGY
B82B: NANO-STRUCTURES; MANUFACTURE OR TREATMENT THEREOF
B82B 1/00: Nano-structures
B82B 3/00: Manufacture or treatment of nano-structures



Recent development of micromachine-related technology (Up to June 11, 1999; Including 99 unpublished patents)

Examples of micromachine-related technology with patent classification (B81, B82)



Technical Terms in Micromachine Technology (v1.0) — Part 4

This is the fourth issue we publish a glossary of key terms excerpted from MMC Technical Report: Technical Terms in Micromachine Technology (MMC TR-S001(01)-1998), which was published by MMC. For more detailed explanations, please refer to the Technical Report.

Silicon fusion bonding
【シリコンフュージョンボンディング】

[DEFINITION] A technique of bonding hydrophilized substrates made of silicon, oxidized silicon, and so on by primary hydrogen bonds between the surfaces, and then by Si-O-Si bonds after annealing at high temperature.

[DESCRIPTION] Silicon fusion bonding is used to form impurity diffusion layers or insulation layers inside a wafer by bonding two silicon wafers; one or both of which may be oxidized. The technology is also used to bond wafers that contain impurities of different species or concentrations, as an alternative process to in-depth impurity diffusion or epitaxial growth where high temperatures and long process time are required. The main problem with silicon fusion bonding is its high process temperature; all lower-temperature processes have to take place after the bonding. Brisk studies are ongoing to lower the process temperature by the application of plasma oxidation treatment before bonding, and to apply the technology to bond non-silicon materials. By bonding oxidized wafers, the silicon on insulator (SOI) structure can be obtained, in which an insulation layer is sandwiched by two silicon layers. The SOI structure is used to separate integrated element components by oxide and other dielectric materials to improve performance; for example, to manufacture photodiode arrays and so on. Another application of the technology is bonding wafers that have been bored or cut grooves in, to obtain precise structures made inside a wafer. This technique is used to make pressure sensors, or heat exchangers for laser diodes with internal cooling structure, and so on. **[References]** (4)

Anodic bonding【陽極接合】

[DEFINITION] A technique of bonding a glass substrate, which contains movable ions, and a substrate of silicon, metal, and so on. The substrates are softened by heat, and bonded by the electrostatic attraction of an electrical double layer produced by applying a high voltage across the substrates with the silicon side as the anode.

[DESCRIPTION] High precision bonding is achieved due to the bonding process at the substrates' solid state. The bonding strength largely depends on the flatness of the surfaces, although this is not as critical as for silicon fusion bonding. Bonding silicon wafers with materials such as Pyrex glass enables structures with internal cavities, such as capacitive pressure sensors and micropumps, to be fabricated. When bonding two silicon wafers or a silicon wafer and a metal wafer, a thin glass film is formed on the contacting surface of the wafers, or the surface of the silicon wafer is oxidized. The problem with the use of thin films is that at high bonding temperatures, the dielectric breakdown voltage of the films is lowered to the point that sufficient voltage cannot be applied. To reduce the process temperature to room temperature, attempts are being made to form a glass film with a low melting point by sputtering. This solves problems such as the strain and deformation caused by thermal stress, and introduces benefits such as the improvement on precision and the wide choice of materials.
[References] (1)(2)(3)(4)

Non-contact handling【非接触ハンドリング】

[DEFINITION] Grasping and moving objects without contact.

[DESCRIPTION] For example, it is general practice in cell manipulation to suck up cells with a glass micropipette and handle them mechanically, but this contact damages the sample and/or changes the physical and chemical conditions. One method of non-contact handling is laser trapping. With this method, the pressure of the light to the object (radiation pressure) manipulates the object without contact or damage. According to electromagnetic theory, the force generated by a 1 mW-laser beam is 7 pN. **[References]** (59)

Micro-manipulator【マイクロマニピュレータ】

[DEFINITION] A mechanism to manipulate microscopic objects such as genes, cells, microcomponents, and microtools.

[DESCRIPTION] Micro-manipulators can be driven by mechanical, pneumatic, hydraulic (oil or water), electromagnetic, or piezoelectric actuator as well as by electric motors. Micro-manipulators for cell manipulation generally combine two separate drives: one for fine movement and one for coarse movement. Most micro-manipulators are manually controlled by visual information received through microscopes or cameras to adjust their micro-position. Future development of micro-manipulators with force control mechanisms is expected for assembling microscopic objects using micro-force and for realizing micro-teleoperation systems.
[References] (1)(2)(4)(5)(6)
[Related Terms] Micro-manipulation

Biochemical energy【生物化学エネルギー】

[DEFINITION] Energy that is stored in in vivo substances and released through chemical reactions.

[DESCRIPTION] Living organisms use chemical energy for mechanical work and transportation and synthesis of substances. Adenosine triphosphate (ATP) plays a core role in chemical energy exchanges. An ATP molecule stocks energy for a short period. For longer storage, carbon hydrate, protein, and fat are used. Performance of the micromachines can be improved drastically if these chemical energy sources can be utilized as energy source for micromachines used in vivo.
[References] (61) **[Related Terms]** Energy source, ATP (Adenosine triphosphate), Mitochondrion

Aspect ratio【アスペクト比】

[DEFINITION] The ratio of the vertical dimension (height) to the horizontal dimension (width) of a three-dimensional structure, used as an index to the relative thickness of the structure.

[DESCRIPTION] It is accepted that silicon process is not appropriate to form three-dimensional structures of much depth, because it is difficult to manufactur structures of an aspect ratio over 10:1. By the use of anisotropic etching or LIGA process, deep holes, grooves and so on of an aspect ratio of 100:1 or greater can be obtained.
[References] (1)(3)(6)(7) **[Related Terms]** LIGA process

Scanning probe microscope (SPM)
【走査プローブ顕微鏡（ＳＰＭ）】

[DEFINITION] Any microscope that uses a probe with a tip of atomic scale and scans it in a raster pattern close to the specimen for measuring physical quantities between the probe and the surface to obtain image.

[DESCRIPTION] By approaching a sharply pointed probe tip to the surface of the specimen, various physical forces that work between the probe and the specimen can be measured at a resolution of an atomic scale. In general, the probe is moved over the surface of the specimen in a raster pattern while keeping the measured physical quantity to a constant level, and the displacement of the probe in doing so is used as the data for drawing a fine image of the specimen. This is the common principle of different types of SPM, that is, the scanning tunnel microscope, atomic force microscope, electrostatic force microscope, scanning ion microscope, scanning magnetic field microscope, scanning temperature microscope, and scanning friction force microscope.

[Related Terms] Electrostatic force microscope

Microscopic surgery, Micro-surgery
【マイクロサージェリー】

[DEFINITION] Surgical operation performed under a microscopeview.

[DESCRIPTION] One attractive technique today is surgery performed under a stereoscope. While the technical term for this is microscopic surgery, in Japan it is called micro-surgery. Microscopic surgery is practiced in otolaryngology, ophthalmology, neurosurgery, vascular surgery, plastic surgery, and other areas. Currently, surgery of the smallest scale is performed in suturing arteries, veins, and nerves with a diameter of around 800 É m using needle and thread with a diameter of around 20 É m. However, because surgeons must manipulate the needle holder, forceps, and scalpel by hand and perform the same actions as in ordinary surgery, these sizes of blood vessels and nerves are considered to be the limit. Therefore micro-teleoperation and other micromachine technology holds considerable promise for the future. **[References]** (4)(5)(6)

[Related Terms] Catheter, Fiber endoscope

Smart pill【スマートピル】

[DEFINITION] A robot that performs measurement and drug delivery inside the body.

[DESCRIPTION] A currently proposed example is the gastrointestinal tract smart pill. This smart pill includes a sampling device that takes samples for measuring, a drug reserver and releasing system, and an intelligent sensor circuit and a controller fabricated on a silicon wafer as well as a micro-power supply.

[References] (4)(6) **[Related Terms]** Intra-vascular vehicle

Active catheter【能動カテーテル】

[DEFINITION] A catheter that can reach its destination by bending freely with a mounted micro-actuator in response to external control signals received.

[DESCRIPTION] If a catheter could bend freely and reliably inside winding tubular organs with internal passageways in response to external manipulation, diagnostic or therapeutic tools could be easily inserted into parts of the body through blood vessels. To realize the active catheter, various micro-actuators and micro-mechanisms will have to be developed.

[References] (1)(2)(4) **[Related Terms]** Fiber endoscope

Micro-factory【マイクロファクトリ】

[DEFINITION] A small manufacturing system in comparable scale with the small products.

[DESCRIPTION] Small equipment such as watches, cameras, and cassette recorders contain many components of a few millimeters in size. Up to the present, such miniature components were processed and assembled by meter-order machine tools or assembly robots. Accordingly, in the process-ing of microcomponents and assembling by such meter-order manufacturing systems, the power required for the movement of the machine tools and assembly robots themselves is much higher than that required for processing and assembly of the small equipment. In addition, compared to the size of the components and products, extremely large amounts of space and resources are required for this manufacturing system. The manufacturing system technology to produce these microcomponents and products using various kinds of micromachine technology corresponding in size to the objects is called micro-factory technology. Compared with conventional production systems, micro-factory technology can achieve substantial savings in energy, resources, and space. **[References]** (19)

Pipe inspection micro-robot
【管内点検マイクロロボット】

[DEFINITION] A robot inserted into a pipe to inspect abnormal sections.

[DESCRIPTION] Microrobots that move inside pipes to inspect abnormal sections are the most promising applications of micromachines. Pipe inspection microrobots are described as follows: they have one or more sensors and travel inside pipes, find abnormal sections, and specify the abnormality type and its location. The two travel types under consideration are the floating type, in which the microrobot travels with the fluid flow inside the pipe, and the self-locomotion type, in which the microrobot travels by an active locomotion mechanism. Each of these methods is further divided into cabled (with a wire for energy supply, communication, etc.) and cableless microrobots.

[References] (19)