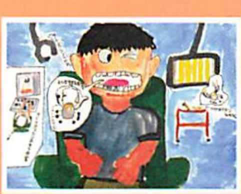
1999 2

MICROMACHINE

- Putting 1999 into Perspective
- University of South Australia
- 4th Internat. Micromachine Symposium / Micromachine Exhibition / Abstracts of Basic Technol. Res.
- Members' Profiles
  FUJIKURA LTD. / Fuji Electric Co., Ltd.
- Foreign View
  MST 98 in Potsdam / IARP Workshop in Beijing
- Introductory Course
  Portable Micromachine Exhibits (IV)
- Micromachine Terminology Glossary Published

MICROMACHINE CENTER



MICROMACHINE CENTER

No. 26

Putting 1999 into Perspective

Katsusada Hirose
Director-General, Machinery and Information Industries Bureau,
Ministry of International Trade and Industry

Happy New Year to all.

Japan's economy is still having a hard time, with negative growth for two consecutive years.

The machinery industry including automobiles, electric and electronics, and industrial machines have been the driving force of Japan's economic growth, whereas the information industry has recently grown rapidly to yield ¥50 trillion. These industries are both crucial to Japan's economy. My opinion is that the healthy development of the machinery and information industries will be the key to the recovery of Japan's economy.

The government drew up the Urgent Economic Measures in last November to bail out the economy and ensure positive growth for fiscal year 1999. Based on the Measures, the third supplementary budget of fiscal year 1998 includes technical development measures for semiconductor manufacturing processing for example, and massive investment in machinery and information venture industries.

As to taxation, corporate taxes and income taxes will be cut considerably, and other taxation measures will be adopted to encourage investment in personal computers and trucks which have significant ripple effects that instantaneously stimulate demand in other sectors.

With these measures, the government is going to concentrate on recovering business as soon as possible.

If a healthy national economy is to be restored, such measures must be led to medium- and long-term growth. To ensure this, three things have to be done: First, we need to promote information technology for higher efficiency and development throughout the entire economy and society. Second, we have to create new industries with very good prospects and high added values. Third, we must build an economic system that can cope with environmental restrictions and resource limitations arising in further economic growth.

It has been noted that the gap between Japan and the U.S. in IT investments is widening. And we are expecting the big wave of digital technology. Our first task, promotion of IT in the economy and society, will be done by three approaches.

The first approach is to help IT spread in industries through electronic commerce, in the public sector through use of IT in schools and in the Intelligent Traffic System (ITS). The second approach is for the smooth development of advanced applications: next generation IT will be developed and environments will be prepared to overcome information society problems such as unauthorized access, thereby paving the way to an advanced information and communication society. The third approach is to secure workers for the advanced information and communication society, by providing IT training to all groups of people in the senior venture support project and the information related talent education project based on the new business creation promotion act (temporary name) approved recently.

Apart from these, the Y2K bug issue will be taken care of, chiefly for small and medium businesses which are less prepared for it.

For the second task, creation of new industries, dramatic future growth is expected in the fields of aerospace, new manufacturing technology, and medical and welfare, let alone in the information and communication areas.

Especially in the aerospace field, as full-fledged commercial use of space advances, demand for satellites is expected to rocket. To meet this need, the SERVIS project is going to start in fiscal year 1999 to conduct surface tests and space demonstrations to reduce manufacturing costs of artificial satellites.

For the third task, to cope with various restrictions regarding the environment and resources, we will enhance environmental conservation and energy-saving measures by promotion of clean-energy, low-pollution, and fuel-efficient automobiles, as well as development of energy-saving LCD technology. To build an economic system to cope with stricter resource preservation in the future, recycling will be encouraged across industries. For example, conditions will be prepared for enforcement of the law for recycling of specified kinds of home appliances approved last year, and reuse of parts will be further promoted by the used car recycling initiative.

Through these measures, MITI is going to focus on immediately stimulating the economy, and do its best for the development of the machinery and information industries for the next generation and the recovery and growth of the economy into the 21st century.

I hope this will be a happier year for Japan.

Microengineering at the University of South Australia

Professor MR Haskard
Microelectronics Centre, University of South Australia

BACKGROUND

The Microelectronics Centre (MEC) at the University of South Australia had its beginnings in 1970 and from the outset had a strong practical bias. Thus research was to have a strong applied side and there would be a need for the establishment of in-house fabrication facilities and the ability to interface into other foundries. On the design side staff established expertise in both analogue as well as digital VLSI design, the former including the design of on chip sensors with interfacing electronics. Early in the 1980s a strong link was formed with the Analysis and Sensors Group (ASG) within the School of Chemical Technology and sometime later the two groups joined with a third sensor group (principally involved in the development of physical sensors) to form an Australian Research Council sponsored research team called the Sensor Science and Engineering Group (SSEG). This group has now ceased operation, but the links between MEC and ASG are as strong as ever.

With this background, staff of the Microelectronics Centre quickly realised that technologies related to, but also outside microelectronics were very necessary to make fully integrated sensor systems. The thrust of the Centre became more focused on microengineering with microelectronics seen simply as a subset of this. Although other terms such as MEMS are used, the Centre believed that the technology was relevant to all disciplines and that it was really engineering in nature, but on a micro scale. Hence the decision to use the term microengineering.

Several underlying philosophies are believed to be foundation stones to microengineering work at the University of South Australia.

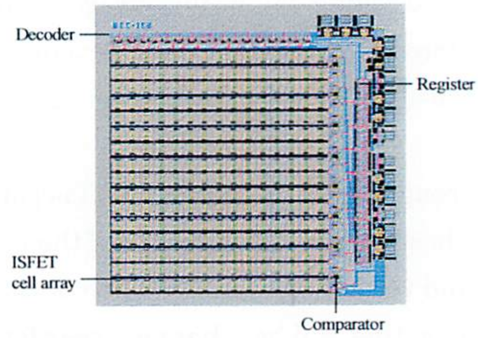
- While microengineering may have grown out of the microelectronics industry, microengineering is a more generic technology and has relevance to all disciplines.
- Examining the growth of the microelectronics industry, two important facts can be recognised and it is believed that both likewise apply to microengineering.
  - Moore's Law anticipates a continuous rate of growth in IC complexity. We have been through the stages of SSI, where basic components and subassemblies were made through VLSI to ULSI, both of the latter allowing totally integrated electronics systems. With microengineering we are just emerging from the SSI stage where components and small subsystems such as motors, pumps, pipes, valves and vessels can be made. However, some quite complex systems are appearing and in the same way one can now have a million plus components on a single integrated circuit, it is, for example, potentially possible to place a whole chemical system of complexity similar to a refinery onto a microsystem substrate.
  - The dramatic exponential growth in microelectronics only occurred when a generic IC was produced, namely the microprocessor. It became the basic building block that not only allowed electronics to build new systems, but also to diversify. Microengineering will only achieve the same result when generic systems start to appear. Every discipline will have its own general system. For example a chemical system might incorporate a gas chromatograph and a mass spectrometer. A mechanical generic system could be a robotic arm/hand.

  These two facts make it essential that emphasis urgently be given to the creation of totally integrated generic microengineered systems; such systems may or may not include integrated electronics. This is not to underrate the part played by basic microengineered components, for these are the stepping stones to systems.
- While the physical world is perceived as analogue rather than digital, such is not always the case. The Centre believes that, as in conventional electronics, there are many advantages in using digital array structures to perform analogue functions. This concept has been applied to a pH sensor for taste-sensing applications, where there is a considerable improvement in system reliability, and to accelerometers where the electronic component is considerably simplified.
- All technologies are relevant. While great emphasis has been given to silicon technology, other electronic technologies such as thick film and even printed circuit board technologies have their place in composing microengineering systems.
- Computer aided design, including system simulation is essential. Since microengineering involves so many disciplines, the CAD systems will be several orders more complex than that for IC design. The ability to extend to non orthogonal shapes for layout software is also essential.

With these philosophies in mind, the Microelectronics Centre with the Analysis of Sensors Group have directed much of their activity to producing microengineered components and systems. Several Australian Government grants have been won that allowed collaboration with South Korean and Indonesian universities and government research facilities in those countries. The following are examples of this work.

Chemical Sensing Arrays

Both amperometric and potentiometric arrays, with all electronics integrated, have been designed and fabricated. An ISFET sensor array (256 IFSET devices with reference electrodes) forms the basic unit for a taste sensing system. The ISFET array itself can monitor sourness. With a matching micromachined array of cavities placed over the ISFETs, filled with an enzyme and coated with a membrane the array can serve as a biosensor detecting sweetness (glucose, sucrose and fructose).



Layout of ISFET Sensor Array Chip (Yeow et al, Sensors and Actuators, B, **44**, 434-440, 1997)

Micropumps

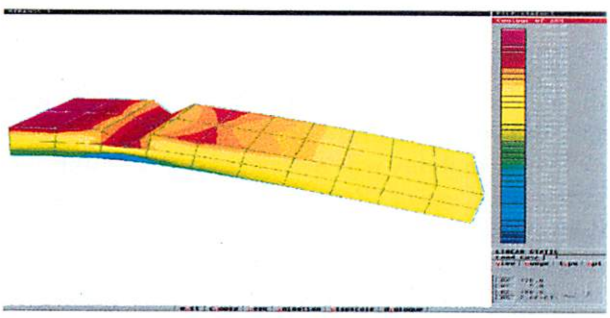
Most chemical microsystems require at least one pump. Initially hydrostatic and in the last few years diaphragm pumps have been researched, designed and built.

Environmental Monitoring System

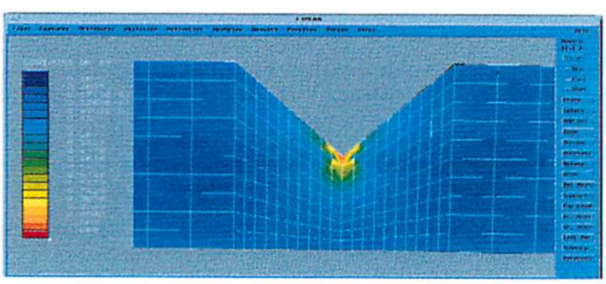
Water and air pollutants are to be monitored in remote areas with minimum servicing. The microengineered system allows self diagnosis and self calibration. The integrated electronics analyses incoming readings so that a minimum amount of information need be recorded, reducing memory size. The liquid pollutant detection system will utilise thick film technology, having up to eight electrodes and a reference electrode in operation at any one time. Present work is focused on sulfide and pH detection. To detect pollutant gases a micromachined gas chromatograph is being developed that utilises both a thermal conductivity (generic) sensor and gas specific sensors.

Accelerometers

Two types of accelerometer have been designed. The first, a four beam system, can have either an analogue capacitor sensor or a series of 20 threshold switches, each designed to switch when a particular acceleration is exceeded. The second sensor, a simple cantilever system, is designed to rupture when the specified acceleration is exceeded. The rupture causes an electrical path to go open circuit, similar to a rupting fuse.



Computer simulation of the level of stress and strain on one of the cantilever beams used in one of our accelerometer designs (Truong et al, Fail-Safe Accelerometers for Airbags, MEC Annual Report 1996)



Crack growth analysis at the fracture point (Truong, et al, Fail-Safe Accelerometers for Airbags, MEC Annual Report 1996)

Field Emission Displays

Field emission displays offer performance equal to that of a conventional CRT and are of flat panel form. They do have the disadvantage of small size, but with so much hand held equipment and a growing interest in virtual reality displays there is still a very large market. The research has been directed at forming and driving silicon field emission arrays having tips treated to give low work functions.

Surface Cracks in Materials

Integrity of structures is important in many fields, particularly aerospace and marine. Where a material is conducting one way of ascertaining whether or not cracks are forming in it is to implant inductor sensors in the surface of it and eddy currents are used to monitor changes. Finite element analysis shows that the "Focused Field" eddy current sensor improves crack detection by around 27%. Further modeling showed that the eddy current sensor could be significantly reduced in size and micromachining production methods become relevant. A new sensor incorporating two micro-coil eddy current units within the same shielding has been designed.

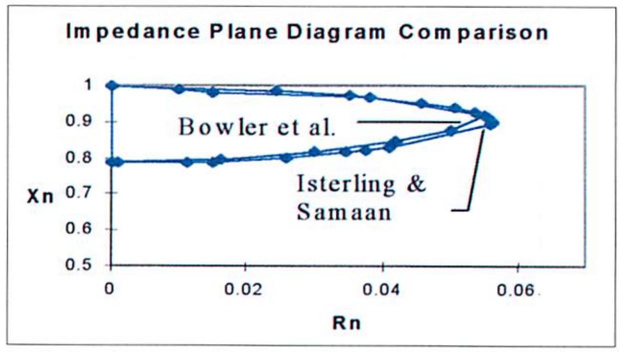


Fig 1: Reproduction of Impedance Plane Diagram (Isterling et al, Sensors Array for On-Line Monitoring of Structural Integrity, MEC Annual Report 1996)

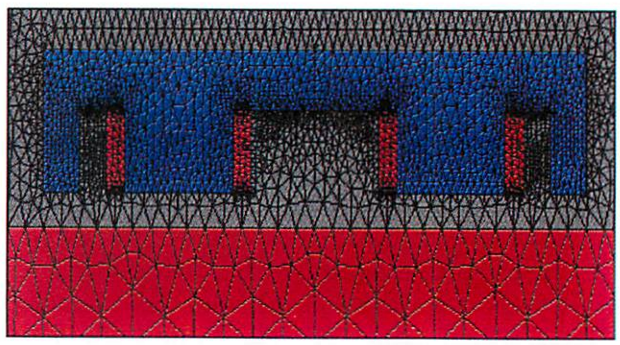


Fig 2: Finite Element Mesh of Dual Eddy Current Sensor (Isterling et al, Sensors Array for On-Line Monitoring of Structural Integrity, MEC Annual Report 1996)

A Microengineering CAD System

A totally integrated multidisciplinary CAD system allowing mechanical, electrical, thermal or any other simulation to be undertaken is being assembled. Such an approach is essential for the design of a microengineered system. Wherever possible either commercial or proven simulation software from other universities is employed, the project involving writing the shell. The design example currently being utilised as the test case is a diaphragm type pressure transducer with some integrated electronics.

CONCLUSIONS

The Centre remains active in microengineering and believes that the field has a bright and long term future. It will only be able to achieve its full potential by continuing its active networking with groups in other Australian universities and research organisations and consolidating and expanding its overseas links.

The Fourth International Micromachine Symposium is Held

The Fourth International Micromachine Symposium was held on October 29 and 30, 1998, at the Science Museum in Kitanomaru Park, Tokyo.

At the opening on October 29, Mr. Katsusada Hirose, Director-General, Machinery and Information Industries Bureau, MITI and Mr. Takeo Sato, Director-General, AIST, MITI gave guest speeches. Also, a greeting from Mr. Hideyuki Matsui, Chairman of NEDO was read by Mr. Hiroshi Mitsuoka, Director. Participants registered for the two days totaled 441, including 53 people from 19 countries (guest speakers included).

Prof. Teru Hayashi, the dean of Faculty of Engineering, Toin University of Yokohama, gave a special guest speech titled "The World of Micromechanisms." Prof. Hayashi is a pioneer in micromachine technology in Japan, and anyone would be interested in his tales of struggling pioneers in the field. He and his colleagues had to develop micromachines by a trial-and-error method coping with unexpected difficulties; prototypes failed to do the designed work because of effects that are negligible at conventional machine scale, and they had to prepare entirely new design theories. He noted that there are many challenges but the smaller the machines, the higher the added value and the better the resource- and space-saving effects, which makes micromachine technology very valuable to a resource-scarce Japan. It makes sense that micromachine technology deserves attention and investment to create an optimal industry for the country.

On the first day, apart from Prof. Hayashi, 16 guests including seven from abroad were invited as guest speakers. Each gave impressive speeches.

Guest speakers from abroad:

- Mr. Gaetan MENOZZI / NEXUS, EC
- Mr. Lean-Christophe ELOY / YOLE Development (France)
- Mr. John HUIGEN / Bionic Ear Institute (Australia)
- Ms. Karen W. MARKUS / MCNC (USA)
- Prof. Wen H. KO / Case Western Reserve University (USA)
- Dr. Jean-Jacques GAGNEPAIN / CNRS (France)
- Dr. J. Michael RAMSEY / Oak Ridge National Laboratory (USA)

A photo taken at the scene of The 4th International Micromachine Symposium

In Session 3, "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 "Rersearch & Development on Micromachine Technology" which is the national project of Industrial Science and Technology Frontier Program. This was followed by an overview from Mr. Makoto Okazaki (Director for Machining 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. Kazuhisa Yanagisawa, chairman of the Research Committee of MMC. Technology trend survey results were announced by three study group heads of the Research Committee. Another eight presentations were given on results from ISTF.

The content of the symposium and the way in which it was organized were highly praised by participants from both home and abroad.

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

The 5th International Micromachine Symposium
Scheduled Date: October 28 (Thu.) and 29 (Fri.), 1999
Scheduled Location: Science Hall (Science Museum B2F), Kitanomaru Park, Tokyo

"Schoolchildren and Micromachines"

Naomasa Nakajima
Professor, The University of Tokyo

Thank you for your kind introduction.

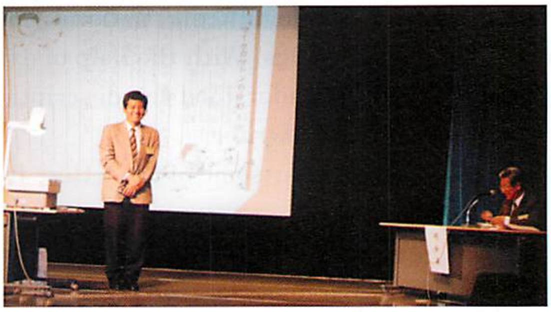
I had an opportunity to write an essay titled "The Dreams of Micromachines" for a textbook for fourth graders. The textbook is not about science or technology but about Japanese, which I was least good at when I myself was a schoolchild. I guess they got the idea of letting me speak here from my essay, so it'll be pertinent to briefly explain how it happened.

Recent Japanese textbooks take up not only novels and poems but also description topics. A description is a text that describes a particular subject. They say descriptions are intended to teach children objective, logical understanding of specific subjects by reading descriptive documents. Textbook editors say what is important for a descriptive essay in a textbook is the subject; if the subject is not interesting to children, class hours will be boring. Editors take great care in choosing a good subject for descriptive essays, since the choice may affect the sales of the textbook.

Here is the textbook I wrote my essay for. It's the second of the two-volume textbook for fourth graders, and I assume the kids have just started this book. I wrote an essay of about 10 pages, titled "The Dreams of Micromachines."

I assume many of you read the magazine "Science for Children" when you were little. This magazine featured the world of advanced robots in June 1992. I was asked for something for the issue, and wrote about the micro robot I had just started studying then. This article attracted the attention of a textbook editor who was searching for a subject for a descriptive essay, and he contacted me. Thus the micromachine went into the textbook to meet the schoolchildren. So this textbook editor was the first to have an idea of an encounter of schoolchildren with micromachines.

A descriptive essay in a textbook must be such that the children reading it can have a proper image and understanding of what is written. To ensure this, the writer employs metaphors using



items familiar to kids to help them to set the exact image. Two things are required by the kids, however; one is reading comprehension to follow the logic of the text, the other is preparatory knowledge to grasp clear images of the content of the text. Reading comprehension is vastly determined by grammatical knowledge, whereas understanding the content requires sufficient preparatory knowledge. Without this knowledge, kids cannot get up the image of what is written, which can be a great problem to any writer of a descriptive essay for kids. Whether the kids can grasp the correct image from the essay is an important point.

I had some opportunities to talk with school teachers who use this textbook in their classrooms. Some schools let children write their impressions of the essay and send them to the author, me, as a part of their Japanese studies, so I receive the impressions described by the children. So far, I have received hundreds of these letters from children all over the country, from northern Hokkaido to southern Nagasaki. Judging from these letters and direct information from school teachers, much to my pleasure, I am sure the children have grasped the exact image of the micromachine. I'm curious from where the children got their preparatory knowledge, which was my biggest concern. I assume it's from robots. Children understand robot mechanisms quite well from their toys. They also know the features and motions of robots from animated movies on TV. Such knowledge of robots can be a good basis for understanding micromachines. Simply speaking, micromachines are fingertip-sized intelligent robots, and children seem to readily miniaturize in their imagination the ordinary scale robots they know already, when inspired by my essay. I assume, with confidence, that children have little difficulty making imaginary reductions of things. With the help of existing robots, children understood the descriptions written by an amateur writer.

You may wish to hear some of the letters from these kids.

Here is one. This kid writes, "I want to be a micromachine researcher. Hang on there till I get there, Prof. Nakajima." This is the exact reaction I hoped to get.

"The Dream of Micromachines" is a short essay of only some 10 pages, but they take 20 hours to scrutinize it. In the 20 hours, the kids not only read it but write their impressions of the essay. Children seem to be interested in both micromachines and In the author from various points of view. Here is another letter from someone who seems to be interested in why I got into the study in the first place, and asks if I was inspired by the Idea, "If you had a wife, she must have a lot of trouble cleaning up your room." Another letter is titled, "You work so hard, Prof. Nakajima," in which the kid says "How are you, are you still working hard studying micromachines? We fourth graders are also working hard." "Working hard" appears frequently in children's writings. It seems that the phrase is important for fourth graders. Probably their parents and teachers, and even the kids themselves, use this favorite phrase of encouragement.

Yet another kid seems to be very interested by the studying "The Dream of Micromachines." At the end of his impressions, this kid wrote an important pronouncement, "I was very disappointed that micromachines are still in the study phase." Put an other way, this kid is expecting much from our research, we have much to harvest. This is an honest and straightforward wish for usable micromachines.

Another boy worries, "What if a micromachine goes out of order in one's tummy?" and "What if a micromachine makes some mistake when treating one's tummy?" To tell the truth, I received many questions about failures. I'm proud to see the kids writing logically in general, showing much interest in micromachines, and growing up to be possible successors to our dream, but I'm a bit worried so many children share common concerns about failure. If the Wright brothers had read this textbook, do you think they would worry about the failure of micromachines? Probably not. Nor James Watt or Thomas Edison. I believe these people would have used their brains to realize their dreams. I myself had no such thoughts when I was a little boy. Therefore, I'm a little concerned that modern kids may be too conservative or even skeptical of the development of technology and creative activities. In a pessimist's view, kids seem to have lost their challenging spirit, with fears of failure. On the other hand, these children may be more farsighted than the kids of my time. They have a perspective on technology and evaluate it in terms of its impact upon the environment and relation to society. If this allows children to work their imaginations to failure, we can be optimistic. I can't judge which view is correct, perhaps they are two sides of the same coin. From these observations, I came to think it necessary that technology education should shift its focus from where it used to be when I was a student. Creative activities require both meticulousness and boldness, which must be balanced. Meticulousness, including being prudent, scrupulous and careful, has been emphasized in education so far. At present, the Faculty of Engineering of the university I work at is divided into 21 departments. I think such a division of the faculties is one expression of the pursuit of meticulousness. Children today are already very meticulous and are ready to accept scrupulousness. Therefore, I think, we need to emphasize boldness from now on. My view is that education of technology should stress letting students take risks.

This is what I felt when communicating with children. Children have various dreams about micromachines and eagerly hope they will come true some day. I'll continue to work hard till these children can continue the research. Let's work hard, my colleagues, and please give a hand to whomever you can.

Thank you for listening.

"Insects and Micromachine"

Ryohei Kanzaki
Assistant Professor, University of Tsukuba

I'm Kanzaki at University of Tsukuba.

Do you know how many species of living things there are on this planet? Millions, in a rough estimate. Surprisingly enough, 80% of all the existing species are insects. The number of insect species is estimated to be over 1.80 million. Insects, as you all know, are relatively small, many fly, and walk on six legs. I invite you into the small world of insects, where a pebble is a huge rock to you. An ant, however, climbs the rock without toil as you see. In the sky, flies can be seen in aerial acrobatics. And you may witness these acrobats caught in the air by a better one, a dragonfly. Insects are small, living in a microcosm, and performing dynamic activities day after day, in various scenes. You may well be interested in the world of insects. They do numerous things in their small world. They have the wisdom to survive in various environments. What a great pleasure it would be if we could experience their world. Insects have five senses just like us. They have sensors to detect smell in the ambient, mechanical stimuli such as wind, and sound, light, and taste. They appropriately receive the information of the varying environment and display an optimal reaction accordingly.

What is more interesting is that the activity of an insect is controlled by tiny nervous system in it. An insect has a brain, just like a human. Both brains consist of units called neurons. There is little difference between the neurons of a human brain and that of an insect brain. However, these brains are much different in how the neurons are organized, and how many neurons are used. The number of neurons in an insect brain is 10 to the power 4 to 6, usually of the order of 10,000. In contrast, a human brain has about 10 billion neurons. Yet, insects have excellent functions to act in the environments which they are adapted to. There is more to the wonder this is insects: Insects emerged on this planet about 400 million years ago. This is a fossil of a dragonfly as old as 15,000 years. This one is grasshopper and that one is a horsefly. And here is a kind of beetle. Seeing these fossils dating back hundreds of millions years, we immediately know which is a dragonfly and which is a grasshopper, which means that insects changed little in their shapes. They seem to have little need to change their morphological and structural features. Over the long period they have survived, there must have been various environmental changes, but the insects stayed unchanged. Let's look at the cockroach. Roaches emerged on the earth about 250 million years ago. Since then,

they have persisted as roaches, what is known to us as roaches today. Meanwhile, the environment changed much and some species emerged and have gone away. Roaches survived with little change. This means that roaches long ago completed their structure and functions to adapt to the environment. What if we could scientifically analyze these astounding mechanisms of insects, and technically reassemble them to create tiny robots adaptable to the environment on the scale of insects. Surely it's a great dream we would like to realize.

I'll show you how an insect processes environmental information and expresses reaction, using a moth for an example. This is a silkworm moth. We make silk from the cocoons of this moth. The moth smells using these antennae, which are the equivalent of our noses. Female moths emit an odor, pheromone, which makes male moths excited. When a male moth smells the odor, he starts searching for the source. Some of you probably remember the Entomological Souvenirs by Henri Fabre, in which male moths locate and come to a female moth over miles. How do they follow the smell, then? Think how we locate the source of a particular smell? Imagine, in the dark, you smell a leak gas. How would you locate the leak? Perhaps you keep in mind how strong it smelled at a given moment, and compare it with previous memories of moments, and go to the direction of the stronger smell. Probably we proceed toward the source by repeating such a process. However, maybe you know from experience, it is very unlikely we humans can locate the source of any smell like this. In contrast, insects can, over a distance of miles, following only the smell. How do they do this? Do they keep a memory of smell intensity at the moment and compare them, like we do? Probably not, because the capacity of the insect brain is by far limited. The tiny capacity does not allow them to employ the advanced functions of memory and learning which our huge brains do. The difference in capacity makes a difference in strategies and information processing method. Insects in their small world must have their own inventive strategies and appropriate command mechanisms. Related to this issue, an important discussion took place in the 1980s: how is smell distributed in the air? You may imagine that smell is continuous and gradually thins out as the distance from the source increases. In reality, however, this is not true. As shown on this figure, smell is not continuous in the air. So, pheromone emissions from a female moth are not continuously received by a male. The male receives pulses of intermittent stimuli, called a filament, and recognizes the chronological pattern of varying frequency. This pattern turns out to be the crucial key to their quest for the smell source.

Experiments on insect behavior in various frequency patterns revealed two ground rules of smell quest. One is that at the moment when the filament of smell molecules in the air hits either antenna, a programmed network residing in the central nervous system is activated to trigger continuous action. This is an example of what zoologists call a programmed behavior pattern. This moth, upon receiving of an instantaneous stimulus to its antenna, moves in the direction where the stimulus was applied. Smell is a momentary pulse on a filament, which disappears instantly. The behavior, however, is programmed and the program keeps on running. This makes the moth move right and left in a zigzag pattern and finally in a circular pattern. Each time the moth makes a turn, the curve it draws grows significantly bigger. Interestingly, this pattern is reset whenever a new stimulus is applied, and the program restarts from the beginning. As a result, this simple algorithm moves the moth in various motion patterns such as moving to the right and left and making consecutive turns increasing the angle of the turn. For example, the moth moves in space where filaments occur at varying frequencies as shown here. At higher frequencies, the mechanism causes repeated frequent forward motion and small turns, which approximates a beeline. On the contrary, at lower frequencies, the moth shows complicated walking patterns like the one shown here. Thus, the quest of a smell source by insects requires little of a complicated memory and learning mechanism, but is instead realized by the simple process of starting and resetting a programmed behavior.

Needless to say, such a mechanism is formed by the neural network in the brain. The network has almost been completed studied. The body of an insect is segmented into three parts: the head, thorax, and abdomen. This brain is in the head. This one is in the thorax. Insects have distributed brains, in different parts for different purposes. The brain in the thorax controls all the motor functions headed to walk and fly. The brain in the head merely sends signals, to turn right or left, and the like. This signal is sent via two tubular nerves leading out from the brain to the thoracic motor system. The status of each nerve is whether it is excited or not excited. If one nerve is stimulated, it gets excited, and stays in an excited state until the next time it is stimulated. By the next stimulus, the nerve changes to the non-excited state, and stays in that state until yet another stimulus is applied. This is a biological flip-flop circuit that works in the brain of an insect. The right and left nerves are always in the opposite state of each other, so that the pair consists of the type T flip-flop in the brain, to issue commands to search for the smell source. You must be curious how such a circuit is formed in the brain. This photo is a cross section of the brain. For easier view, the cells are stained. There are only a small number of nerve cells, so we can follow each nerve fiber. Scrutiny under a confocal laser scanning microscope, clarifies the stereoscopic structure and the network. Flip-flop information is formed by this network via a particular region in the brain shown in this photo. Researchers have found that such a network consists of eight groups of neurons. We actually fabricated a smell-follower robot of a similar size to the moth, incorporated in it the control circuit I've explained, and used the real antennae of the moth as the sensor to see if the robot shows the same zigzag motion and turns like the moth. Yes, as you see, the robot searched for the smell source in the exactly the same pattern as the insect. To date, much has been studied about this neural network. We came this far to collect in vivo data of a flying insect using a telemetry device mounted on it. In the near future, we will be able to control the insect at will by stimulating its nervous system by feeding the received data back to the telemetry device.

My point is, insects are small creatures, yet they survived natural selection over a long period and are thriving today in various forms adapted to various environmental conditions. As a result, having very simple nervous system and being basically only capable of acting according to their natural program, insects somehow acquired intense interaction with the environment, and possess excellent behavior patterns that make them seemingly intelligent, as if they were acting according to some criteria of decision making. We believe insects will be an excellent model for making robots that adapt to and work in microenvironments.

Thank you for listening.

"Origami May Reveal Idea of Micromachine Structures"

Yoshihide Momotani
Professor, Kyoto International University

Thank you for your kind introduction.

Some of you must be wondering what origami is. Origami is the art of folding paper intricately into decorative forms. I prepared some color slides.

What you see are traditional patterns devised about 200 years ago. The one on the right end is called Yakko, a man in a kimono. The one in the middle is the crane, the most popular pattern in Japan. On the left is an iris flower. Here is another also fabricated about 200 years ago. In this scene, a monkey is sitting in the middle, and various figures of the time are shown behind. This one is a dancer, for example. This piece was meticulousness by fabricated centuries ago. However, since then origami has been adopted by elementary schools as a part of education, where the art was simplified as child's play.

I'll show you some modern origami. Here are familiar dinosaurs. The one on the right end is intended to be Godzilla. Mr. Kanzaki has told us about insect brains, and I wish when he makes one, he would implant it in this origami insect. Wouldn't it be fun? Origami can make tiny things.

Look at this one. This biplane is made of a single piece of paper, without cutting it. Origami can express mechanical forms.

The next one is Santa Claus. Isn't it amazing that folded paper can render this expression on his face?

This flower is not real. You may suppose folded paper can only produce straight edges, but actually origami can also be used to make such realistic flowers.

Now then, how is origami related to micromachines? Making a micromachine takes steps.

First, you must prepare precision components, each of which has a three-dimensional structure. Then you have to put them together exactly to a designed arrangement. The accuracy of the assembly of micro components is one problem. And a possible solution is to let the parts assemble themselves. This will save us lots of labor. Self-organization, I call it, is what I'm searching for.

My own field is biology, so let me explain with some examples of living things.

Enzymes found in the bodies of organisms in general have a simple structure of a straight chain of tiny units called amino acids. An enzyme does not show its functionality while it's in the straight chain form. But amino acids on the chain have property of developing stereo structures on their own to render a specific functionality to the enzyme. I conceived of the possibilities of doing the same using origami. Origami is a manual art in the ordinary world, but my idea is the self-organization of origami. So, there are two possible uses of origami for micromachines: One is the fabrication of tiny stereo structures, and the other is assembly, hopefully by self-organization.

Let me do a little demonstration. This is nothing uncommon, it is the popular crane pattern. Wait for a bit while I unfold this. Here, a single piece of flat, paper. Please watch care-fully now. Voila! The piece of paper restored the stereo crane pattern in an instant. Once the paper is creased, it can restore the folded form instantly. I'll show you again. You see, this is a piece of square paper. I just hold one corner, and without folding, the structure is brought back in a moment. This can be applied to the construction of some precision structures. Preparing some creases in a relatively large object, and applying a little force to one part of the object will fold it into the designed form.

I'll show you another handicraft. It's called momigami, or paper-crumpling. This art is almost extinct now, though. First, I roll up this ordinary piece of paper. Now I crumple this end, then the other end, then this end again, and the other end again. This is the simplest technique of momigami. Now the paper has been crumpled into a small lump. When unfolded, you can see the neat repetition of the hexagon pattern. This momigami used be used to decorate sliding doors in Kyoto.

The next one is a sort between origami and momigami. It may seem as an array of units on a silicon base. It is unfolded by pulling the ends. The original form is restored by moving the ends back. You don't need to touch the middle part. Just rock it a bit, and the original shape is restored. Now I extend it again. This was made possible by developing origami and momigami techniques. I call it repetitive pattern origami. If you look closer, you can see the stereo structures in it. Transformation from the piece of paper into the three-dimensional shape is reversible, and vice versa. Planned positioning is crucial, and accurate positioning is reproducible no matter how many times you extend and contract it, just like momigami. I think it would be possible to form three-dimensional structures instantly by preparing such pattern creases on a thin silicon sheet, not by folding but making thin regions on the design, then applying force.

You've seen some interesting things reproduced by origami. I'll show you more complicated ones on the screen.

This is a hydrangea flower. The entire cluster is made of a single piece of paper, excluding the leaves.

This one was made about 30 years ago. It looks like a flower, but actually it's a mathematical pattern called a fractal, in which similar figures are infinitely repeated into the figure.

At first sight this also appears to be a repetitive pattern. Bricks laid in a horizontal direction. But because of the gradual changes in the creases, on the other end the bricks are an edge. It was modeled on the drawings of M. C. Escher.

This is a 3D model of a DNA molecule, in the double helix structure. A DNA molecule is stable when it's in the double helix form. This model is made of a single piece of paper.

This one is also made of a piece of paper. The tobacco mosaic virus is thought to be shaped like this. This hexagon part represents a single protein molecule. Many such molecules are arranged to form the helix that wraps up the virus.

This is a model of the cytoplasmic membrane. The lipid membrane is here, with holes of proteins. This is also made of a piece of paper.

I'm very interested in micromachines, and I'm a biology lecture using these molecular models, so I enjoyed talking here today.

I hope you enjoyed it too. The last piece is a funny one. This is the white rabbit in Alice in Wonderland, running with his leg watch.

Thank you for listening.

Exhibition "Micromachine '98" Held

The 9th Micromachine Exhibition "Micromachine '98" was held successfully with The 4th International Micromachine Symposium. The three-day exhibition was held from October 28 to 30, 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 77, 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, we provide Theme Exhibit featuring "the Future of Health and Medical Service through Micromachine" to familiarize the ordinary people as well as the professionals with the micromachine. This theme exhibition was divided into three zones, Low Invasive Diagnosis and Therapy System, Health and Home Care, and Life Support Systems. Spectators got a glimpse of how micromachines will provide "Health" and "Medical Service" in the future with the display of models and human figures.

In the general exhibition, major items were micromachines, their components and application systems, MEMS related systems, molecular machine related technologies, micromachine manufacturing related equipment and materials, micromachine evaluation technologies and equipment. These specialties were intended for participants engaged in research and development, technology, design, production and manufacturing, and management in serious fields including machinery and precision instruments, electric and electronics appliances, medicine, information processing and communication, automobiles and transportation, biology, physics, chemistry, construction, steel making, aviation and space, and shipping and oceanology.

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.

The exhibition was covered the press. An NHK news program, Ohayo Nippon (Good morning Japan), broadcast the Micromachine Exhibition live for about four minutes from 7:45 on October 28. In the program, the ISTF program projects and future feasibilities of applications were explained concisely with some results. The ones featured were the micro servo motor of Yaskawa Corporation and the chain-type micromachine for inspection on outer surfaces of tubes developed jointly by Mitsubishi Electric Corporation and Matsushita Research Institute Tokyo, Inc. The micro servo motor was incorporated in a roulette wheel and stopped it precisely at a specified position. The chain-type micromachine for inspection of outer surfaces of tubes powerfully shoved a ¥1 coin that weighed twice as much as the machine. The accurate movement and work must have impressed many in the TV audience.

Visitors totaled about 3,900 over the three days. With many sparing much time to observe exhibits and asking questions to the staff, the place was crowded and filled with excitement.

Schedule of next exhibition "Micromachine '99"

Period: October 27 (Wed.) to 29 (Fri.), 1999
Place: Science Museum, Kitanomaru Park, Tokyo
Inquiry: MESAGO Japan
Tel.: +81-3-3359-0894
FAX: +81-3-3359-9328
E-mail: KYP03300@nifty.ne.jp
URL: http://www.mesago-jp.com

Exhibition full of inspectors from Japan and abroad

Theme exhibition

Research on Basic Micromachine Technology for Fiscal Year 1997 (Part II)

Since 1992, the Micromachine Center has taken up 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 1997, research has been carried out on eight themes. Continuing from the last issue, the remaining four themes are summarized below.

Research on Group Control and Signal Transmission in Organisms

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

Animals, especially ones like insects, display relatively simple behavior such as reflex and fixed action pattern (or instinct behavior)[1, 2]. However, social insects like honeybees and ants employ communication and task sharing among individuals in a group, to impart high functions unavailable to a single individual, thereby forming sophisticated social organizations[3].

Living things are considered to have evolved through natural selection[3], to acquire structure and functions fit for the size of the body[4]. The mechanisms of signal transmission used by insects and the group structure based on it should be usable for designing and controlling micromachines.

Insects, just like humans, can sense the external world as light, sound, smell, taste, and tactile. Sensory information is first accepted by sensory organs, and processed by the central nervous system including the brain then the motor pattern of the insect is released. In an insect, 90% or more of the total neurons comprising the nervous system including the brains are sensory neurons. This implies that sensory organs of insects play important roles in establishing communications[1].

Honeybees, typical social insects, have various ways of communication in their colonies, such as individual-to-individual information transfer by sound and vibration, and multiple-step information distribution typically by the bee dance which begins with individual-to-a-few, then proceeds to individual-to-several, multiplication of channels by individual-to-individual, to final bilateral communication between any two of all the members.

An individual honeybee does different social tasks at different stages of life in the hierarchy of its society, starting from hive cell cleaning to looking after larvae, taking care of the queen bee, storage of food, expansion and improvement of the hive, gate keeping, and foraging. Therefore, the same information communicated has different meanings depending on the age of the bee.

The social structures (groups and colonies) of honeybees may seem to be controlled by equivalent identical and orderly signals. However, living things always use redundant and loose signals so as to make room for options to adapt. The greatest difference between insects and a micromachine is that insects reproduce themselves and have evolved their functions through natural selection. Scientific technology dislikes waste, and the homogeneity of a group of robots disagrees with adaptive evolution through natural selection of varying individuals. The flexibility of insects towards their environment relies much on the brain and nervous system that controls their behavior. So far, however, very few organic autonomic systems have adopted the internal status of living things.

At present, much energy is put into the research of brain functions of insects. Some studies have controlled small robots using brain function models. The study of micromachines modeled on internal mechanisms and structures of insects has started only recently. In front of us is a hatching egg, and much is expected for application of the research results to the design and control of micromachines and their group structures.

References
1) Ryohei Kanzaki: Dreams of Insect Robots (illustrated by Katsuhiko Shigeri, edited by Kenji Umetani), Nobunkyo (1998)
2) J. Alcok: Animal Behavior (5th edition), Sinauer (1993)
3) D.J. Futuyma: Evolutionary Biology (2nd edition), Sinauer (1986)
4) K. Schmidt-Nielsen: Scaling — Animal Design Theory (translated by Tateo Shimozawa, et al.) Corona (1994)
5) Kenji Umetani: Insect Industry, Agriculture and Fishery Technology Information Association (1997)

Worker honeybee (Apis mellifera) returns from foraging and dances to signal a good source of food
(The dancer makes 250 Hz signal sounds during its waggling run. The followers are aiming their antennae attentively toward the dancer to "listen.")

Research on Fablication Techniques for 3D Micro Structures using Particle Assembly

Tomomasa Sato
Professor, Research Center for Advanced Science and Technology, The University of Tokyo

Structure fabrication techniques from fine particles, such as pottery or ceramics, are familiar to us from ancient days. Nevertheless, they have been hardly applied to fabrication of micro structures. In this research we considered the feasibility of micro fabrication by particle assembly, which utilizes particles naturally produced by crystal growth or atomization as component parts, and clarified the problems to be solved.

Fabrication from fine particles can be classified into four techniques as follows:

(1) molding technique which uses geometrical constraints of molds (such as ceramics molding, screen printing, or jet molding from nozzles),
(2) patterning technique which uses adhesive pattern (such as xerography),
(3) assembling technique of individual particles (particle assembly discussed here), and
(4) structure growth by self-organization just like crystal growth.

Particle assembly technique has the advantage that it can produce micro structures as designed with the accuracy of particle size. On the other hand, it is not suitable for mass production. Consequently it should be applied to special functional devices which cannot be realized by other methods.

Particle assembly is further classified into noncontact manipulation utilizing laser radiation pressure and contact manipulation under observation with various kinds of microscopes. All of these types are still under development and are too immature for industrial use. Among them, contact manipulation technique under optical microscope and that under electron microscope are considered to be practical for producing functional devices. Each technique covers different scale ranges, i.e. manipulation under optical microscope should be applied for assembling particles larger than several micrometers and that under electron microscope should be used for much smaller particles.

Particle assembly cannot be implemented even though a micro manipulator with enough accuracy is combined with a microscope with sufficient resolution. The problem lies in dynamics rather than in apparatus. Presently both microscopes and manipulators already have enough resolution for observation and manipulation of particles, respectively. The present research topic is to understand how to pick up a target particle reliably and place it accurately at the desired position. This may sound trivial for us because we are accustomed to the dynamics in the macro world.

As the size of an object reduces, the gravity force working on the object sharply diminishes, since gravity is proportional to the cube of the scale. In contrast, electrostatic force and intermolecular force, which are insignificant in daily life, emerge as dominant forces. These forces give particles the tendency to adhere to other objects. The lack of precise knowledge about the mechanisms of such adhesion left us not knowing how to manipulate the particles at will, i.e. how to pick up and place particles with good reproducibility. One may succeed in picking up a particle with precise tweezers, but cannot place it to an accurate position because the particle stays adhered to the tweezers. Although various theories have been established to explain adhesion forces, they are applicable only in limited, ideal situations. Our past studies revealed such theories cannot survive in an actual particle assembly environment. What is needed to establish particle assembly is not further development of precision manipulation systems, but rather the study of particle adhesion phenomena in reality and the establishment of control technology of particle dynamics.

We are systematically investigating adhesion phenomena observed during particle assembly in electron microscopes by measuring the adhesion force with the resolution of 1 nN. To date, we have clarified that electrostatic force is dominant under electron microscopes as expected, the force varies greatly depending on the surface roughness, and the adhesion increases as time passes because of the development of interface affinity (probably at the atomic scale). Thus, complex factors and phenomena are involved, which are not considered in existing theories.

After particle manipulation technology is established based on an understanding of these phenomena, particle assembly will be an important complement to other micromachining technologies.

Study on Chemical Analysis and Sensor Technology (μTAS)

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

Recently, micro total analysis systems (μTAS) researches have been active mainly in Europe and North America. A typical μTAS is a chemical analysis system miniaturized by micromachine technology, in which the sample injector, carrier and sample flow control pumps, reagent mixer/reactors, component separation columns, and sensors are integrated. An example of μTAS diagram is shown in the figure. The benefits of μTAS are the small requirements of samples and reagents and its quick analysis, let alone the size reduction. In early stage, there used be proposals for monolithic systems where all devices would be incorporated at the wafer level, but at present hybrid systems to which independent devices are connected via O-rings are preferred for better practicability. Some reports point out the satisfactory benefits of miniaturizing not all the existing analysis system components but some. For instance, small battery-driven chemical analyzer systems have been developed by combining reagent mixers and analysis cells formed by micromachining with existing small pumps and other components.

In the field of analytical chemistry, recently a new technique called capillary electrophoresis (CE) has been attracting attention for its excellent separation efficiency, by far better than high-performance liquid chromatography (HPLC). Many researches are carried out on analyzer systems that use flow channels formed on glass or silicon substrate by micromachine technology instead of the conventional glass capillaries. These types of systems exploit electroosmosis to feed liquid, which makes the system structure simple compared to that mechanical pumps and valves.

Fluid control devices such as micro pumps and micro valves with various types of actuators have been developed, and are being studied for practical use. Non-mechanical devices that use electrophoresis and surface tension are also under study.

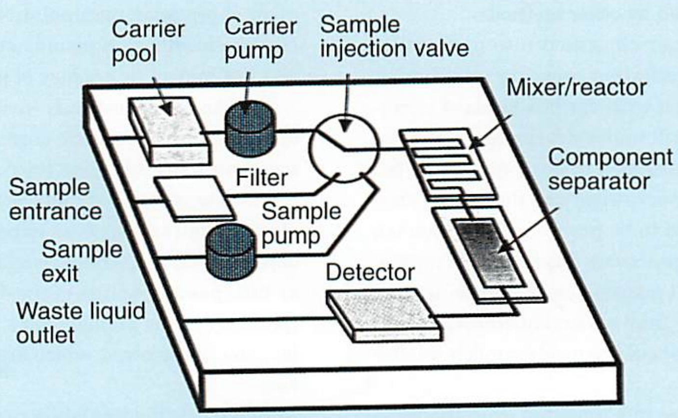
Micromachine technology is used broadly to form extremely fine flow channels and for fabricating micro pumps and micro valves, as well as for micro sensor integration and μTAS assembly.

Mainly in the US, μTAS research aiming at DNA analysis becomes popular. This owes much to the establishment of the polymerase chain reaction (PCR) technique for amplifying DNA analytical information. A micro reaction chamber with a small heat capacity made by micromachine technology enabled quick, efficient DNA amplification. Reports from this field frequently announce systems that first separate components by electrophoresis followed by fluorescence analysis using laser excitation. To improve the analysis speed and efficiency of these systems, simultaneous multiple detection by multiple electrophoresis channels formed in parallel is being studied. Another DNA analysis technique in focus is the use of DNA chips which have single-chain DNA probes in different combinations formed on the substrate. Micromachine technology is also being energetically applied to biology, and advantages such as the small scale, high space resolution, integration and parallel formation of multiple devices, improved handling of samples and reagents by integration with mechatronics technology are being studied.

In the future, through tighter cooperation of micromachine researchers with colleagues in the fields of analytical chemistry, pharmacy, and medicine, the development of practical μTAS with higher functionality is expected.

Reference

Shuichi Shoji: Electronics Information and Communication Society Journal, Vol. J.81-C-I, II, No. 7 (1998) 385-393



Schematic of a μTAS

Study on the Applicability of Molecular Machines as Micromachines

Masamichi Fujihira

Professor, Faculty of Bioscience and Biotechnology, Tokyo Institute of Technology

The research assigned to our committee was:

(1) Survey of molecular machine feasibilities in the cells and genes of organisms

(2) Survey of applicability of molecular machines as micromachines

Following a discussion by the committee members, these themes were integrated as the survey of molecular machine feasibilities at the level of cells, proteins, and genes. Proteins were added because we came to know that the joint research team of Professor Masasuke Yoshida of the Tokyo Institute of

Technology and Professor Kazuhiko Kinoshita of Keio University were successful in their direct observation of F1-ATPase rotation, which plays a crucial role in energy conversion in organisms, and reported it to Nature[1].

To take advantage of the expertise of the members, Akaike surveyed cells for molecular machine feasibilities, Fujihira and Yamamoto did proteins, and Handa genes. We took care to have close communication between the four members. Each theme alone is a huge system of knowledge and cannot be covered in a short period of time. Therefore, we decided that each team leader would hold seminar style meetings to discuss their individual standpoints of study.

(1) Survey of molecular machine feasibilities at cell

Connections between cell biology and micromachines are multi-faceted and profound, and have high potential for future applications.

Various analytical instruments (e.g. endoscopes, MRI) for the human body and its components such as cells and organs have been dramatically improved thanks to advances in medicine and biotechnology. These machine systems and components as well as their partners, that is, diagnosis and treatment drugs, are reducing in size. This means that the progress of micromachine technology will support the progress of *in vivo* measurement and *in vivo* manipulation. Once impossible devices and equipment known only in fictional stories and motion pictures (such as Fantastic Voyage) are steadily approaching reality.

With such prospects, studies focusing on bioresponse (such as cell signal responses) based on interaction of the interface between artificial materials such as polymer materials, semiconductor metals, and ceramics and living cells, organs, and tissues, are increasing in importance. In this report, we examined an approach that analyses cell response divided not only in dynamic interaction fields but static interaction fields as well.

Another important point in relating cell biology to micromachines is that tissues of organisms are excellent theoretical models for useful micromachine designs in various industries. In other words, the "hardware and architecture" of organic molecules consisting various organs, cells, and cell internal systems are potentially good models should be studied to design highly functional and intelligent micromachine systems. Furthermore, as recent studies consecutively elucidate the mechanisms of signal transmission between organs, between cells, between cell and matrices, and internally within a single cell, their algorithm "software" emerged as possible hint or model for intelligent micromachine system design. Biomimetics, the name of this approach to artificial materials system design and mechanical system design through the study of organisms, is getting familiar. Some even use the term "super biomimetics" for an approach attempting to surpass organisms in some aspects. The five studies detailed in this report are world-class level challenges to analyze interactions between organisms and micromachines, and then collectively present an excellent case study for promoting biomimetics in micromachine design.

(2) Survey of molecular machines at protein level

F1 ATPase in a protein involved in energy conversion in organisms — it synthesizes and consumes ATP — does its work by establishing an electrochemical gradient across the cytoplasmic membrane and rotating itself in the coupling process. We took this fact as a paragon of the unexpected, yet rational way organisms give themselves functionality. In this survey report, we focused on research techniques to investigate molecular machine feasibilities at protein level. Fluorescence spectroscopy and other light-related measuring techniques are very useful for investigating molecular machine feasibilities especially at the level of proteins. Since the recent progress of the scanning near-field optical microscope has significantly contributed to optical measurement and spectroscopy at the nanometer scale, we took up this technique as a subtheme of our survey.

This survey report details the subsequent progress of joint research "Protein and Micromachines — Scanning Near-field Optical Microscope as a Method for Evaluating Structure and Functionality"[1] along with five studies.

(3) Survey of molecular machines at gene level

We selected functional complexes consisting of single or multiple organic molecules likely to be applied as molecular micromachines, and surveyed the current level of basic research on the complexes. This survey is based on "The Cutting Edge of Genetic Study — In Search of a Connection between Bioscience and Micromachines." The six most notable studies on the state of the art in the fields were selected for detailed survey.

The following survey themes were selected and the current level of basic research and the feasibility as micromachines were investigated.

- Functional complexes: transfer machine, latex particles
  - (1) Activity control of DNA-to-RNA synthesis transfer machine
  - (2) Design and application of DNA fixation affinity latex particles
- Single organic molecules: NO_2 metabolizing enzyme (nitrite reductase, NiR), ribozyme, antisense RNA, highly functional artificial evolution tRNA
  - (3) Urban environment restoration and plant genes — feasibility of panel planting using waste gas
  - (4) Structure of ribozyme and application to genetic treatment
  - (5) Antivirus activity by antisense nucleic acids
  - (6) tRNA engineering

This report elucidates the survey results of the six themes above.

Surveying these three fields gave us a new awareness of the amazing ingenuity of molecular machines in living things. My main impression is that the structure and functions of the living molecular machines are so meticulous that direct application to micromachines would be difficult at present. On the other hand, I also got a strong impression that there are many materials that can be immediately helpful for conceptual design and actual materials design if we sort out the major components of the living machines. I can hardly call this work comprehensive, but I hope it will be of some help to researcher intending to deal with micromachines.

Reference

1) H. Noji, R. Yasuda, M. Yoshida and K. Kinoshita Jr.: Nature, 386, 299-302 (1977)

FUJIKURA LTD.

Koichi Inada
Managing Director, Director of
Research and Development Division

1. The Challenge of Micromachine Technology

Recently, Micro Electromechanical Systems using three dimensional silicon processing technology have been energetically researched and developed. To meet current demand, Fujikura is conducting R&D to add to the functions of sensors and the development of new application fields. As a participant in the Industrial Science and Technology Frontier Project, we are also conducting R&D on necessary elemental technologies to implement micro vision.

2. Development of Micromachine Technology

In the ISTF project, we have been engaged in the development of two elemental technologies. One is bonding technology for stacking multiple bare IC chips required for CCD control, onto a three-dimensional structure. The other is the through-holes interconnection technology for transferring electric signals between the chips in a small space.

One requirement of bonding technology is that it must not impair the circuit functions incorporated in the chips. To ensure this, we developed bonding technology using water glass that works at about room temperature and with low external stress (such as electromagnetic field and weight). This technology has made it possible to suppress residual stress on the junction face, making a highly reliable junction that is free from peeling and warping. As an example, the self-packaged infrared micro sensor shown in Fig. 1 was fabricated using the water glass bonding technology. According to the results of accelerated environment and aging tests, the sensor's mean time to failure is six years.

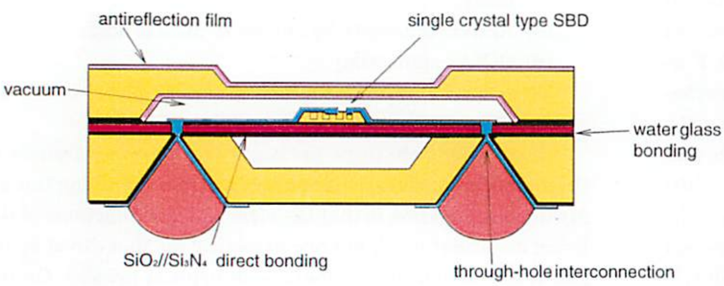


Fig. 1 Cross section view of the self-package type IR microsensor

The other research subject, the formation of through-holes interconnection, requires the through-hole processing technology of an aspect ratio of 100 or greater and a technique to fill the hole with electrode materials. For through-holes interconnection, we selected optical excitation electropolishing method for its low cost and capability of processing at a high aspect ratio. This technology forms V-grooves on silicon substrate and causes an electrochemical reaction (electrolytic polishing) selectively in the specified areas to form through-holes. Technical problems were the removal of the gas produced and how to circulate reaction liquid in the capillaries. To tackle these problems, we optimized the concentration of electrolyte, wavelength of radiation light, and used surfactant. As a result, through-holes with a diameter of 4.4 µm and a depth (length of through-hole) of 480 µm (aspect ratio of 109) were successfully formed. Fig. 2 shows a cross section of a hole under a scanning electron microscope.

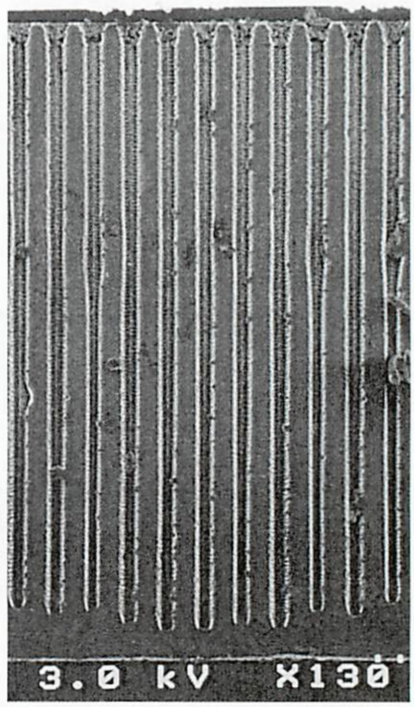


Fig. 2 Cros-sectional view of high aspect-ratio through-holes etched into Si

3. Future Challenges

Research so far has been successful in making good through-holes. At present, we are trying to develop technology to fill electrode materials in the holes. We hope to complete this technology and establish a through-holes interconnection technology with total reliability in the future, to contribute to the implementation of micro vision, which is the goal of the ISTF project.

Fuji Electric Co., Ltd.

Yasuo Tani
Managing Director, Director-General
of Corporate Research Institute

1. The Challenge of Micromachine Technology

A sensor is a typical product of semiconductor processing technology and micromachine process technology. In our product line-up, there are various types of sensors such as acceleration sensors for activating an automobile airbag, pressure sensors for plant monitoring, and gas leak sensors consisting of coiled thin metal wire. These sensors undergo further size reduction and performance improvement by surface micromachining technology using sacrificial layer etching and intelligent implementation using sensors and circuits both mounted on the same silicon substrate.

The actuator, another application of micromachine technology, had a great impact at its advent. However, progress since then has not been smooth. Fuji Electric, as a participant in the Industrial Science and Technology Frontier Project, are trying to solve problems in the practical use of micro actuators.

2. Development of Micromachine Technology

We studied electromagnetic and electrostatic actuators aiming at miniaturization of actuators in phase I of the ISTF project. In the current phase II, we are studying a two-dimensional micro conveyor which uses the elemental technologies developed in phase I.

Fig. 1 shows the electromagnetic actuator fabricated in phase I. The rotor diameter is only 1 mm. The operating principle of this actuator is similar to that of an ordinary motor: electromagnetic force generated in the coil current and permanent magnet. Because of the scale, the coil is made of thin film and the magnet is a thin film magnet made of rare earth elements. This actuator has achieved 24,000 rpm in on unloaded state.

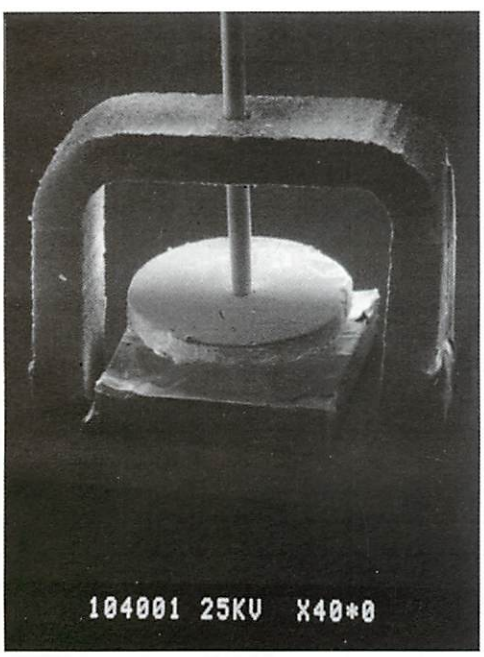


Fig. 1 Micro electromagnetic actuator
(Rotor diameter: 1 mm)

Fig. 2 shows the coil of the two-dimensional micro conveyor under study in phase II. Square coils made of thin film are arrayed on a flat sheet. Each coil is 1 mm long and 30 μm thick. Electromagnetic force between the coil current and the carrier made of permanent magnet moves the carrier on the flat sheet. The coil current is controlled for each coil, making it possible to move the carrier straight, diagonally or rotationally. This micro conveyor is scheduled to be included in prototype systems of the microfactory, an attempt at extreme size reduction of manufacturing equipment, to convey small components as a demonstration of micromachine operation.

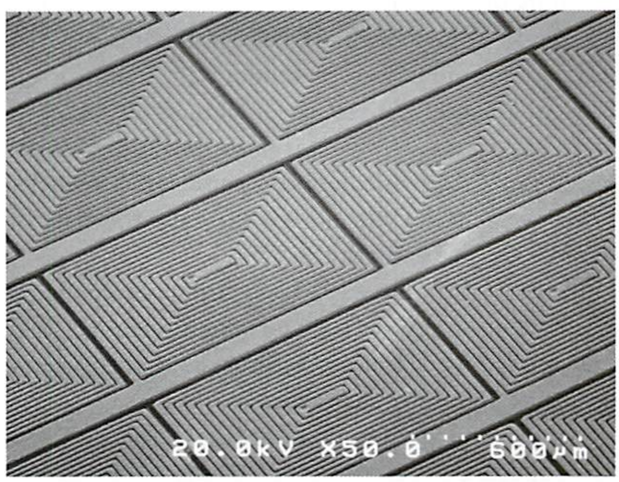


Fig. 2 Two-dimensional micro conveyer
(Side length of a coil: 1 mm)

3. Future Challenges

Micromachine technology is supported by many elemental technologies. We hope to create unique products for the 21st century, exploiting the thin film formation technology and micromachining technology acquired through the ISTF project.

MST 98 Held in Potsdam

MICRO SYSTEM Technologies 98 conference was held from December 1 (Mon.) to 3 (Wed.) at See Hotel, in Potsdam, Germany. About 400 participants attended. Along with the conference, exhibition was held.

As listed below, 139 topics were registered. Participants from Japan were all universities and colleges. They were: Tokyo Institute of Technology, Nagoya University, Kyoto University (2 topics), Tohoku-Gakuin University, and Ashikaga Institute of Technology. The breakdown of the topics was four oral and two poster presentations. Only one presentation by the plenary was made from the US because MEMS 99 is scheduled about two months later in Florida. On the morning of the first day, four tutorials (Microoptics, Modeling and Simulation, Metrology, and Reliability of Packages) were held simultaneously. Opening sessions started in the afternoon. After a greeting from the host, policies on MST were explained in German for about 10 minutes. The reporter heard several Japanese company names in this speech, but was unable to understand the speech in German.

In the opening speech, Prof. V. Saile of Karlsruhe Laboratory discussed the business strategy of LIGA process (using SOR light), Prof. Mizugaki of Kyushu Institute of Technology discussed micromachine technology in Japan, Prof. N. F. de Rooij of University of Neuchâtel reported on MST trends, Dr. J. Marek of Bosch explained applications for automobiles, and Dr. Karen W. Markus of MCNC discussed the latest trends in MEMS applications in the US.

Each country stressed applications in the fields of information processing and communication field and medicine. This conference featured many speeches about optical devices.

Japan enjoyed much attention. Prof. de Rooij introduced the Microfactory of the MMC in his speech, and Dr. Markus explained the ultrasonic sensors of Sumitomo Electric Industries using photos.

On the second and third days, two plenary sessions were given in the morning, then three or four sessions were held simultaneously. The session on the future prospects of applications was the most popular, attracting a large audience that filled the 80 seats in the room. Future prospects of applications for MST in the medical and automobile fields, MST world market scale prediction by NEXUS, and a future scenario were presented and discussed.

Each session had presentations on the latest technologies followed by discussions. Overall, developments related to standardization seemed to have progressed much. For example, the German standard had pre-registration of the structure of fluid sensor modules which supports one connector to a standard electric connector, and the other to a common flow path connector, and incorporates the MST device and the electronic circuitry device in separate BGA packages to be stacked and connected (VDMA 66305 01.98). User opinions will be reflected when establishing the standard.

The focus of optical device development has shifted from devices to fabrication. Standardization of system pallets (magazines) for assembly and a 3D position detection and measurement system are under consideration. This shift shows the signs of new business.

Posters were put up in the corridors of the hotel from the evening of the first day. The corridors were very crowded, but one could see the posters in any spare time during the conference.

Registered presentations in the conference by countries and regions (Tutorials and opening speeches excluded)

Country / Region	Oral	Poster
Germany	69 (2)	28
Japan	4	2
Austria	4	2
Taiwan	3	2
United Kingdom	3	
Italy	3	
Switzerland	2	
France	2	
Belgium	1 (1)	3
United States	1 (1)	
Sweden	1	
China	1	
Belarus		2
Spain		2
Rumania		1
Poland		1
Finland		1
Bulgaria		1
Total	**94 (4)**	**45**

* Those in parentheses are plenary sessions.

Second IARP Micro Robot Workshop Held in Beijing

The International Advanced Robotics Programme (IARP) based on the agreement of Versailles Economics Summit in 1982, started as one of international research cooperation programs to exchange information and opinions on R&D related to robots. The second International Work Shop on Micro Robotics and Systems, an IARP workshop, was held at the China Hall of Science & Technology near the center of Beijing, on October 22 and 23.

The host was Prof. Zhenbang Gong, vice president of Shanghai University. Prof. Min Tan of the Chinese Academy of Sciences (Beijing) administered the secretariat. The entire meeting was presided over by Prof. T. J. Tarn of Washington University, who is of Chinese descent. Among the 39 participants, most were teaching at universities and colleges. The breakdown of participants by country is: 13 from the US (including 5 Chinese descendants), 1 from Germany, 7 from France, 2 from Russia, 2 from Japan, and 14 from the host country China. From Japan, Prof. Toshio Fukuda of Nagoya University and Manager Utsumi of MMC joined.

The meeting proceeded from general to technical talk, and panel discussion was held in the afternoon on 23. In the general talk, China explained situations of development of micro robots in the country. Situations of development of MEMS technology were also reported in a separate speech. France introduced the 4-year CNRS micro system program started last year. Prof. Fukuda gave a guest speech on micro manipulators.

In technical talk, current situations of existing technologies of actuators, manipulators, micro robots, and applications were explained. The MMC reported medical applications related R&D themes in the ISTF project, to gain favor of the audience. The speakers enjoyed questions from and discussion by the audience during the discussion time and break time after the speech, even while moving from the session room to the hotel. The panel discussion was presided over by Prof. Peter Will of the University of Southern California, and the six panelists representing each country gave presentations on micro robot applications and the aims of R&D. The audience joined the following session, providing various viewpoints and making for a lively discussion.

Panel discussion at 2nd IARP Micro Robot Work Shop

Attendants

Country	Name and Affiliation of Attendants
United States	Norman Caplan (IARP President, National Science Foundation), T.J. Tarn (Washington University), C.S. George Lee (Purdue University), Oussama Khatib (Stanford University), Fathi Salam (Michigan State University), Ning Xi (Michigan State University), Peter Will (University of Southern California), T.C. Steve Hsia (U.C. Davis), Ralph Hollis (Carnegie Mellon University), Roberto Horowitz (University of California at Berkeley), Rosemary L. Smith (U.C. Davis), Scott D. Collins (U.C. Davis), Bradley J. Nelson (University of Minnesota)
Germany	Heinz Woern (University of Karlsruhe)
France	H. Camon (LAAS/CNRS), N. Troisfontaine (University de Paris), A. Bourjault (LAB UMR), F. Bastien (Institut des Microtechniques de Franche-Comte), Daniel Hauden (Institut des Microtechniques de Franche-Comte), M. Calin (LAB UMR), N. Chaillet (LAB UMR)
Russia	V.G. Gradetsky (Russian Academy of Sciences), L.N. Kravchuk (Russian Academy of Sciences)
Japan	Toshio Fukuda (Nagoya University), Y. Utsumi (Micromachine Center)
China	Yihui Wu (Chinese Academy of Sciences), Sun Linzhi (Shanghai University), Mei Tao (The Chinese University of Hong Kong), Z.Y. Zhou (Tsinghua University), X.Y. Ye (Tsinghua University), Zhao Wei (Beijing University of Aeronautics & Astronautics), Bi Shusheng (Beijing University of Aeronautics & Astronautics), Zhenbang Gong (Shanghai University), Min Tan (Chinese Academy of Sciences), Wang Tianmiao (Beijing University of Aeronautics & Astronautics), Yang Yinmin (Guangdong University of Technology), Cheng Lianglun (Guangdong University of Technology), Tang Esheng (Chinese Academy of Sciences), Xia Shanhong (Chinese Academy of Sciences)

Portable Micromachine Technology Exhibits (IV)

MITSUBISHI ELECTRIC CORPORATION

"Micro Generator"

1. Development of Micromachine Technology

Mitsubishi Electric develops chain-type micromachines for inspection on outer tube surfaces to check for flaws on heat transfer tubes of steam generators at power stations. As shown in Fig. 1, this system consists of multiple micro units which wind themselves around tubes and move to probe. The key in the development is the implementation of a compact, high-output motor (driving device) along with various system construction technologies.

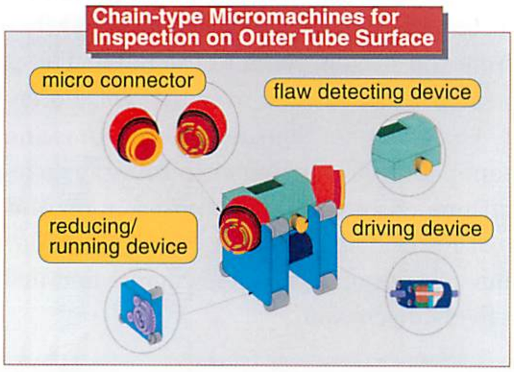


Fig. 1 Micro units

2. Overview of the Portable Exhibit

[Significance of creating the exhibit]

A cylindrical stator housing high-density coil windings and a rotor with a powerful permanent magnet are the key elements in the micro electromagnetic motor used for the driving device. To implement these components, we developed generators for the structure of the motor. The purpose of the exhibit is to show that the tiny generator by far smaller than a finger tip generates electrical output, thereby giving an example of micromachine technology applications to the general public. (Fig. 2)

Fig. 2 Portable exhibit

[Explanation of the exhibit]

Fig. 3 shows the same generator used in the exhibit. The generator measures 1.2 mm in diameter and 2 mm in length. At 300,000 rpm, it produces an unloaded terminal voltage of about 40 mV. The small turbine mounted on the axis of the generator is fastened in a see-through pipe. Press the red switch on the front to turn on the fan, then press the button on the top to let air into the pipe. The turbine starts rotating to generate power, and a digital display of the output voltage appears at the left inside.

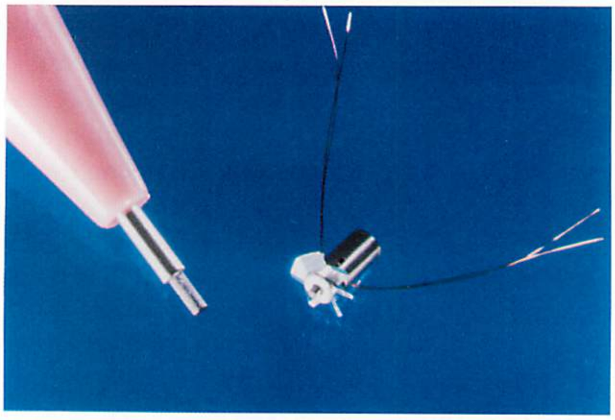


Fig. 3 Micro generator

[Key points in the exhibit]

This world's smallest generator is of the radial gap type, which has a gap between the rotor and the stator in the radial direction. This type of generator yields high efficiency but is difficult to reduce in size. Development of advanced micromachine technology solved this problem. Since the micro generator converts mechanical energy such as ambient fluid flow into electrical energy, it can be used as an energy converter device for mobile micromachines without the need for feeder cables.

3. Future Applications

Various applications of micro generators and micro motors as energy sources or drivers are expected. The technologies for making high-density coil windings and high-performance thin film magnets will help future devices using new concepts and key devices mounted in information and communication equipment or electronic equipment which are rigorously undergoing size reductions and performance improvements. We continue to develop micromachine technology with a good balance of functional elemental technologies and system integration technologies.

Mitsubishi Cable Industries, Ltd.

"Tip-Articulation Endoscope using SMA Micro Coil"

1. Development of Micromachine Technology

Mitsubishi Cables develops the environmental recognition device to implement the visual function in the microfactory, a desktop processing and assembly system for micro mechanical parts. The functions required of the device are microscopic and three-dimensional observation for appearance inspections and size measurements of processed micro components in the machining process and inspection of assembly status in the assembly process (Fig. 1). Development of detecting the position of the tip of the endoscope, tip articulation mechanism using a shape memory alloy (SMA) micro coil actuator, and stereo vision is ongoing to implement this device.

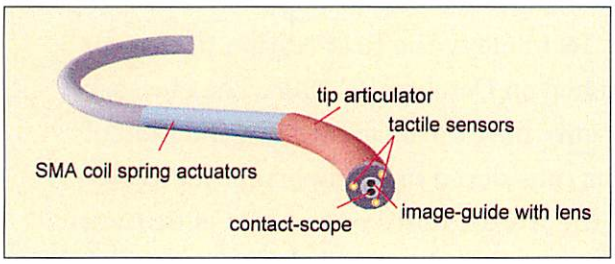


Fig. 1 Environmental recognition device

2. Overview of the Portable Exhibit

[Significance of creating the exhibit]

An ordinary endoscope has a wire attached to the tip of the scope which leads to the hands of the operator so that the tip of the scope can be moved as the wire is pulled. However, if the tip of the scope goes beyond a large curve or far from the entrance, the force of the operator pulling the wire fails to reach the tip. To solve this, an actuator must be placed on the tip to move it on its own. To implement this, we adopted an SMA micro coil for its ease of size reduction and great power output and displacement. By incorporating the SMA micro coil in a thin endoscope to create this exhibit of a tip articulation mechanism, the feasibility of high power actuators working at microscopic scale was proved (Fig. 2).

Fig. 2 Portable exhibit

[Explanation of the exhibit]

Two SMA coils of a wire diameter of 200 μm and an outer diameter of 700 μm were combined to comprise a pair of actuators opposing each other. Two of these pairs are employed to move the tip to the right and left. This set of actuators and a fiberscope with an image guide of 6,000 pixels are combined to make the endoscope of the outer diameter of 2.5 mm and a maximum angle of tip articulation of 60 degrees. Tip articulation by the SMA micro coils and the corresponding changes in view can monitored on a display (Fig. 3).

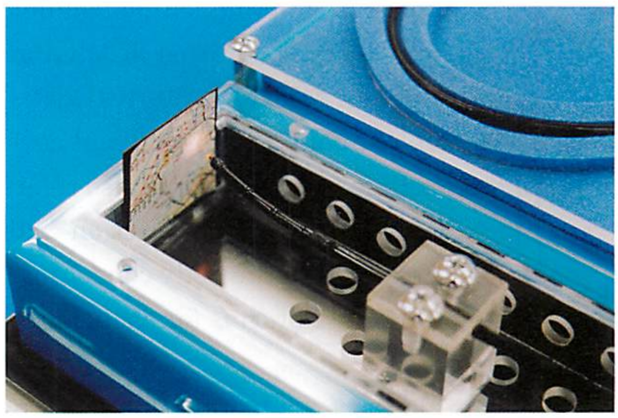


Fig. 3 Motion of tip-articulation

[Key points in the exhibit]

For ease of understanding, the exhibited fiberscope is bent sharply. In this state, where a conventional wired endoscope cannot move its tip, the SMA actuator incorporated in the tip provides a wide view. The image picked up by the endoscope is shown on the display screen, for intuitive understanding of the motion of the tip. Adding actuator control function will make it possible to stop the tip of the fiberscope at an arbitrary position.

3. Future Applications

Taking advantage of the higher functionality without an increase in outer diameter, applications of the fiberscope for medical and industrial purposes are possible. So far, SMA coil springs have been applied in home appliances, living related equipment, and industrial machinery. The SMA coil displayed in the exhibit is smaller than anything of its kind. We are considering applications in wide fields to make the most of its compactness and the accompanying performance improvement.

MMC Technical Report
Micromachine Terminology Glossary Published

Since fiscal year 1993 the Committee on Micromachine Standardization, the Study Committee on Micromachine Standardization, and the Working Group for Terminology at the MMC has been conducting research aimed at standardization on technical terms related to micromachine technology. The results have been compiled a technical report, "Technical Terms in Micromachine Technology the first edition (technical report number: MMC TR-S001(01)-1998)" published on October 10, 1998. The glossary is A5-size of about 180 pages, and covers not only new terms created in the field of micromachine technology but also related terms considered to be important for micromachine technology. The selection criteria of the words, notes on use, classification tables are added to the body consisting of terms with definitions, explanations, references, and related terms for each, both in Japanese and English. Cross referencing is possible.

The glossary is a helpful handbook not only for micromachine technology researchers and those who are about to start their studies, but for the general public as well. The International Micromachine Standardization Forum which commenced last November has started discussions on an international network conference using the glossary as a reference, aiming at international standardization on technical terms in micromachine technology.

MICROMACHINE No. 26

MICROMACHINE is published quarterly by Micromachine Center (MMC) to promote the international exchange of information related to micromachines, R&D and other technical topics, and is circulated free of charge. Please send your comments about **MICROMACHINE** to the publisher:
Takayuki Hirano, Executive Director, Micromachine Center (MMC)
5-F, Niikura Building, 2-2, Kanda-tsukasacho, Chiyoda-ku, Tokyo 101-0048, Japan
Tel: +81-3-5294-7131, Fax: +81-3-5294-7137
Internet Home Page http://www.iijnet.or.jp/MMC/

Change of Address: Please send old address label and new address to the publisher.
Editorial and Production Management: Japan Technical Information Service (JATIS)
Date of Issue: Feb. 19, 1999