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Feb. 1998

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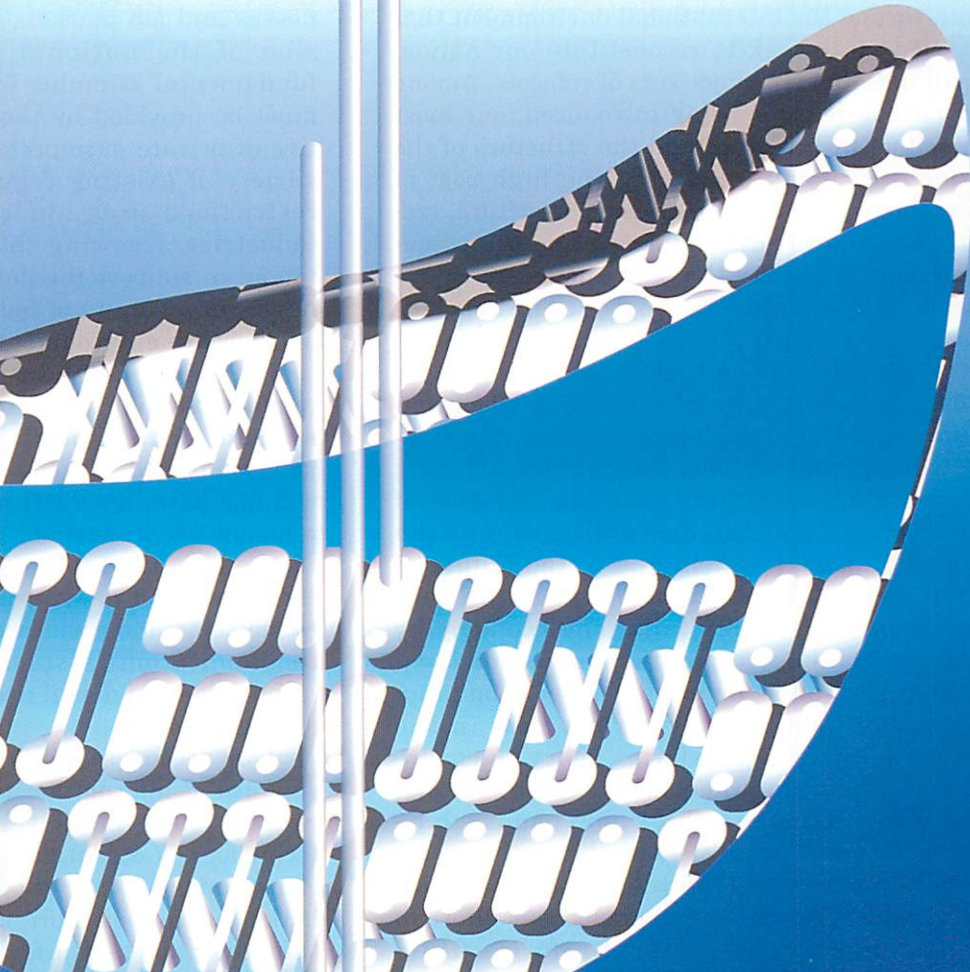
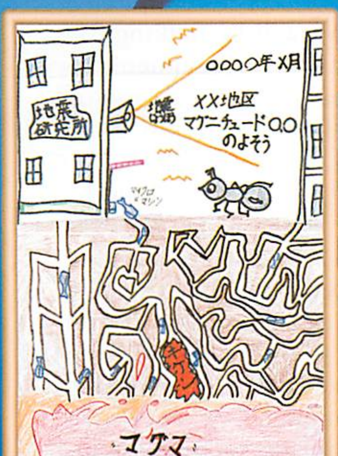
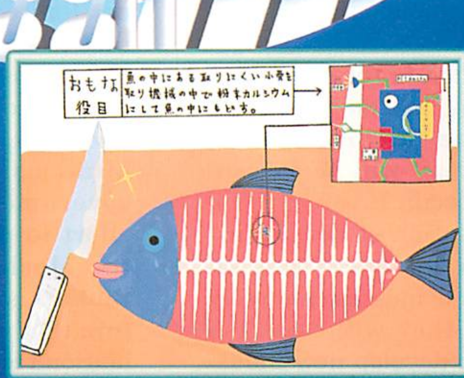






No. 22

MICROMACHINE CENTER

Thoughts on the New Year

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

Please accept my very best wishes as we greet the beginning of the New Year.

Last year, in response to changes in both the domestic and the international environment that have led us to seek to reconstitute our nation, Japan initiated six major sets of reforms. Among the various reforms being introduced, our most compelling task is to reform the structure of the national economy, rectifying the high cost of doing business under the present structure, creating new industries, and recovering the essential economic vitality that can sustain us as we enter a new era of increasingly severe competition.

In addition to the task of achieving these structural reforms, we also find ourselves confronted with the confounding problems of a business climate that remains sluggish due to falling demand and uncertainty over the direction of the economy and the destabilization of the nation's financial system due to the failure of certain financial institutions. The government has taken steps to revitalize the economy by reducing taxes on corporations and individual earnings, as well as by placing a freeze on property taxes, and furthermore is now in the process of enacting a prudent policy to ensure the stability of the financial system by issuing some ¥10 trillion worth of new bonds, to be secured by government-held stocks.

In my own view, 1998 will be a year of enormous challenges as we embark on our effort to achieve mid-term structural reforms while ensuring the stability and expansion of our present economy.

As for our own contribution to the revitalization of the Japanese economy and the promotion of structural reforms, the Machinery and Information Industries Bureau will be concentrating its efforts on three specific areas.

Our first task is the creation of new industries. With the dawning of a new era of international competition in which businesses can freely select the countries where they will establish themselves, it is essential to develop new industries, and this includes incorporating existing industries into value-added enterprises, in order to adequately address the hollowing out of businesses and job markets and ensure the expansion of the national economy. While the fundamental stimulus for this kind of activity must be provided by the efforts and the initiative of private entrepreneurs, the fact is that a variety of existing regulations and technical restrictions often hinder the creation of new industries. Knowing that this is the case, we intend to support the development of new businesses in a variety of fields by helping to create appropriate environments. We will help establish markets for industries supplying items related to social welfare by creating systems to evaluate product standards, for example, and for newly founded content-provider industries we will facilitate the creation of a preferential environment for production. We will be making concrete efforts to supply suitable environments for the creation of new businesses in fields related to medicine and social welfare, information and communications systems, new manufacturing technologies, and civil-use aerospace technology, among others.

Our second task is to promote more extensive use of information technology. In the business world, greater reliance on information technology is essential in order to enhance efficiency and increase productivity, as well as to make businesses more competitive. Moreover, the advantages of information technology are not limited to the public and private sectors – they are helping to improve the lives of ordinary citizens as well. It is this grasp of the situation that led to the establishment of a central authority for the promotion of information and communications technology within the Cabinet. The government as a whole is making an active effort to promote information technology, and the Machinery and Information Industries Bureau is doing its part to provide infrastructure that will enable more extensive use of information technology in both the public and private sectors, especially by setting up our own central office for the promotion of information and communications technology.

For the industrial sector the task of more effectively incorporating information and communications technology is an extremely serious challenge from the standpoint of intensifying international competition. In order to support such efforts, we have been conducting experiments and demonstrations, on the largest possible worldwide scale, with electronic trading. As a means of achieving the full-scale introduction of electronic trading, we are making efforts to popularize integrated information systems that support production, procurement, and distribution (computer-aided logistics systems, or CALS) and electronic data interchange (EDI) systems. We will continue to work to provide environments for development that will propel the greater implementation of information technology in the next century, including the development of the basis for next-generation information technologies and highly advanced leading-edge electronic technologies; for the enactment of measures to protect security and privacy as businesses expand internationally; and for the establishment of systems to deal with intellectual property issues and other such problems.

We will also continue to promote greater use of information and communications technology in the public sector, revising jurisdictional regulations to enable applications and the like to be submitted electronically in order to enhance administrative efficiency and reduce the burden imposed on ordinary citizens. Furthermore, we will make greater efforts to promote more extensive use of information technology in the areas of medical services and education, working in concert with the relevant governmental authorities.

Our third principal task is to address certain environmental issues. The Conference of Parties to the United Nations Framework Convention on Climate Change, held last year in Kyoto, produced an agreement by the participating nations to establish an international framework for dealing with climate change and to set legally binding targets for the active reduction of greenhouse gas emissions by the industrialized nations. This represents an important first step, from a mid-term and long-term perspective, toward the prevention of global warming. It will require the efforts of each related industry for the targets established at the Kyoto conference to be achieved. In addition, the Ministry of International Trade and Industry will assist these efforts through such means as advancing the development and popularization of clean-fuel burning automobiles, promoting research into alternative systems that don't result in greenhouse gas (such as PFC) emissions, advancing the development and introduction of high-performance industrial furnaces, and promoting the greater use of bicycles.

With regard to measures to encourage recycling, we will continue to make efforts to actively promote the effective reusing of resources, by faithfully implementing our initiative for the recycling of used automobiles, which establishes a system for the disposition of discarded autos and sets targets for recycling them; by developing industrial recycling systems (so-called inverse manufacturing systems); and by establishing systems for the recycling of electrical and electronic apparatus.

As I noted above, 1998 will be a year in which, in light of the changing domestic and international environment in which we find ourselves, it will be necessary for the machinery and information systems industries of Japan to once again make a great leap forward in order to maintain their firm footing within the global economy. The Ministry of International Trade and Industry will do its utmost to support the development of cutting-edge technologies and to help provide the necessary environment.

In closing, once again I wish you the very best in the New Year.

Research Activities on Microengineering at Imperial College, London

Prof. Richard R.A. Syms, Dr. Eric M. Yeatman, Dr. Andrew S. Holmes
Optical and Semiconductor Devices Section, Department of Electrical and Electronic Engineering, Imperial College, London, SW7 2BT
http://www.ee.ic.ac.uk

Work on microengineering commenced at Imperial College in 1992, following contact with Japanese researchers associated with the instigation of the MITI Large Scale Micromachine Project. Since then, this activity has grown in parallel with the two other main interests of the Section – integrated optics and microelectronics – allowing an extremely useful technical cross-fertilisation to take place. Links have been maintained with Japan, through exchange of personnel with the AIST Mechanical Engineering Laboratory, Tsukuba, and through project sponsorship by the Micromachine Center. The Section is equipped for device fabrication, having several clean rooms containing semiconductor processing equipment, chemical processing areas and test laboratories. Our current research ranges from the development of new fabrication processes to devices and systems, including the following:

• Silicon Micromachining and Microactuators

We have devised a method of fabricating silicon MEMS based on a combination of surface and bulk micromachining. Only single-crystal material is used, and electrical isolation is provided by back-to-back p-n junctions. The devices are large compared with conventional surface micromachined components (several mm span, suspended 100 μm above the substrate), and have correspondingly large motions that may easily be observed in an optical microscope. Figure 1 shows a typical device. We have demonstrated wide-range electrothermal tuning of mechanical resonances, and are currently developing a coupled-resonator gyroscope incorporating an active frequency-matching system.

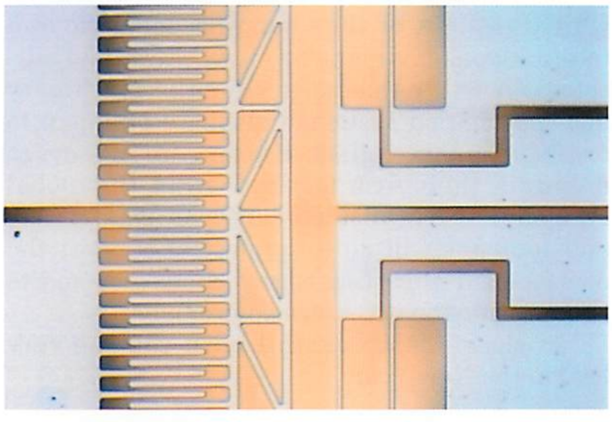


Fig. 1. Bulk micromachined, diode-isolated, comb-drive electrostatic actuator (electrode width: 5 μm).

• Piezoelectric Materials and Microactuators

We have been investigating different chemical routes for the fabrication of piezoelectric ceramics, for use as actuating layers on silicon microstructures. We have recently found an alternative to the sol-gel process, based on metal-organic decomposition. This allows rapid and reliable production of thick PZT films with good ferroelectrical properties, and we are now fabricating bimorph cantilevers based on this material. We have also obtained preliminary results for a new type of microactuator operating by the electrical control of surface tension forces (electro-wetting).

• 3-D Microforming

We have devised low-cost alternatives to LIGA processing based on simple lithography tools. Deep metal microstructures may be built up by repeated application of a standard process cycle comprising 1) deposition of a conducting seed layer, 2) deposition of photoresist, 3) lithography, and 4) metal electroforming. By using this approach, and combining UV contact lithography with excimer laser micromachining, we have realised complex devices such as the six-level nickel microturbine shown in Figure 2, which has structural heights in the range 10 μm to 100 μm per level.

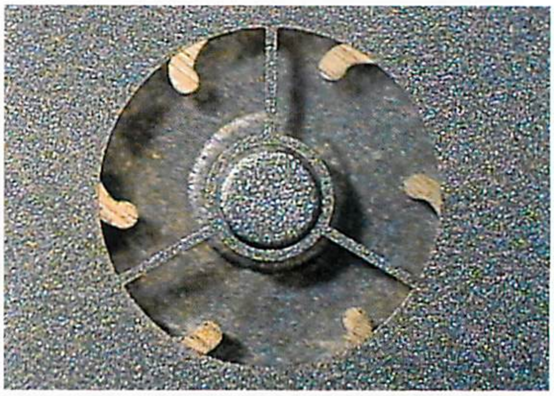


Fig. 2. Six-level electroformed microturbine fabricated using resist moulds formed by UV lithography and excimer laser micromachining (shaft dia.: 200 μm).

• Parallel Assembly

We are interested in the generic problems of the handling of small components and their assembly into microsystems. We have recently demonstrated a wafer-scale parallel assembly process, in which electroformed components supported on optically transparent carriers are detached by using pulsed laser irradiation through the rear side of the cartier to ablate an intermediate polymer layer. Transfer of components from one wafer to mate with components on another is then achieved simply by bringing the two wafers into proximity, aligning them, and then exposing the reverse side of the carrier to detach the required components. Figure 3 shows a typical motor structure, in which the rotor has been mounted on the stator by laser-assisted assembly.

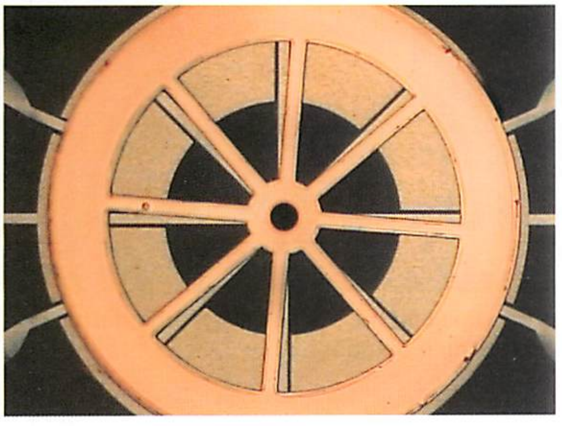


Fig. 3. Wobble motor based on a rotor and stator that have been fabricated on separate substrates and brought together by laser-assisted assembly (rotor dia.: 1 mm).

• Self-Assembly of Three-Dimensional Microstructures

We are also studying methods for fabricating truly three-dimensional structures that cannot be made by lithography and etching (which form only quasi-3D structures). We have demonstrated a method of self-assembly based on out-of plane rotation and fixing of flat parts. Rotation is powered by the surface tension force provided by pads of meltable material linking each movable part to the substrate. Rotation through a fixed angle (say, 90°) may be achieved using a simple mechanical limiter. Figure 4 shows a typical self-assembled structure, based on silicon micromachined parts and pads of low-melting point borophosphosilicate glass. We are now developing applications of self-assembly, such as a folded inductor for high-Q microwave circuits.

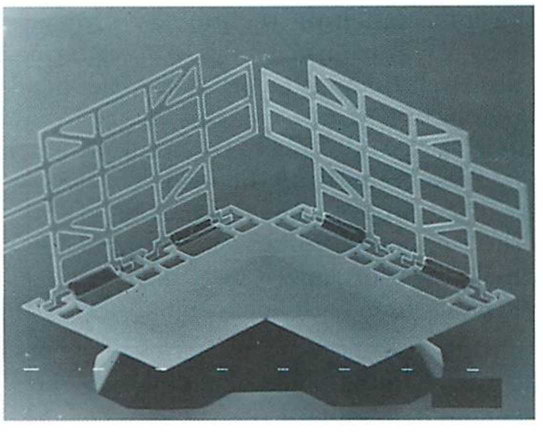


Fig. 4. 3-D microstructure fabricated by out-of-plane rotation of surface micromachined Si flaps using surface tension forces provided by pads of a low-melting point glass (flap height: 300 μm)

• Optical and Optomechanical Devices

Over a number of years, we have developed a unique process for fabricating thick glass layers on silicon substrates, based on the sol-gel technique and the iterative use of spin-coating and rapid thermal annealing. This has allowed us to fabricate silica-on-silicon waveguide components such as couplers and thermo-optic switches, and also to investigate novel materials for enhanced functionality. We have demonstrated optical nonlinearity in a semiconductor-doped glass waveguide, and are also investigating rare-earth doping for optical amplification. Our latest project involves combining waveguide components with microactuators for optical scanning and reading applications.

• Microanalysis Systems

We are attempting to construct silicon-based microanalysis systems. Anisotropic etching of (100) Si substrates is often used to form precision alignment features for locating optical fibres in ribbon connectors. We have used a similar approach to fabricate an alignment assembly for cylindrical electrodes. Figure 5 shows four electrodes arranged in the geometry of an electrostatic quadrupole lens. This lens can be used as an imaging element in an ion optical system. It can also be used as the mass analyser in a miniaturised mass spectrometer, and preliminary demonstrations of mass selection have recently been performed.

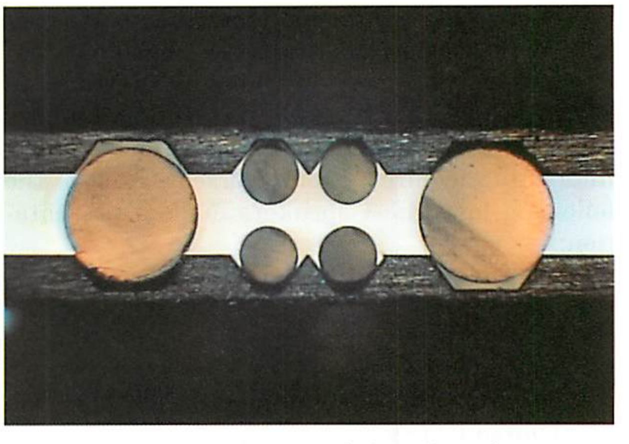


Fig. 5. Quadrupole electrostatic lens based on anisotropic etching of Si (electrode dia.: 500 μm).

Funding for microengineering projects is currently provided by the UK Engineering and Physical Sciences Research Council (EPSRC), the Wolfson Foundation and the UK Ministry of Defence.

The Third International Micromachine Symposium Is Held

The 3rd International Micromachine Symposium, held at the Science Museum in Kitanomaru Park, Tokyo on October 29th and 30th, 1997, was a great success.

On the opening day, Mr. Katsusada Hirose, Director-General, Machinery and Information Industries Bureau, MITI (read by Mr. Makoto Nakajima, Director, Industrial Machinery Division, on behalf of Mr. Hirose); Dr. Takeo Sato, Director-General, Agency of Industrial Science and Technology, MITI; and Mr. Hachio Iwasaki, Chairman of NEDO (New Energy and Industrial Technology Development Organization) each spoke as a guest of honor. There were 423 participants in the two-day session, including 47 from overseas. Participation from overseas included the British government's Department of Trade and Industry, the ITS (International Technology Service) Mission headed by Professor Howard Dorey, Imperial College.

Professor Isao Karube (The University of Tokyo) gave a special lecture on the subject of "Micromachining Technology and Biosensors." He talked that if a low-cost, disposable-type sensor can be invented for use in checking for diabetes, it would represent a break-through for the industry and would also enable the public to become familiar with micromachines. He concluded that such R&D into micromachine technology is very important. On the first day, in addition to Prof. Karube, 14 other members served as guest speakers, and each gave a very interesting lecture. From overseas, each of the following four guest speakers made a presentation:

Mr. Gaëtan Menozzi / NEXUS, European Committee
Dr. Jay Lee / National Science Foundation (United States)
Prof. Howard Dorey / Imperial College (United Kingdom)
Prof. Roberto Horowitz / UC Berkeley (United States)

Professor Dorey, who headed the British government's ITS Mission, was also one of the invited speakers from overseas.

In addition, for Session 5, "Thinking of Micromachine," three speakers who do not specialize in the field of Micromachine Technology were also invited as lecturers. Since those lectures were unique and very well-received, the detail of their talks will be reported in this issue for readers' reference.

A photo taken at the scene of The 3rd International Micromachine Symposium

The second day was dedicated to presentations on the progress of "Research & Development on Micromachine Technology" which is the national project of the 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. The heads of four working groups of the Systemization Committee of MMC gave presentations on their works. Seven reports on the results of the second phase of the project were also presented.

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 4th International Micromachine Symposium
Scheduled Date: October 29 (Thu.) & 30 (Fri.), 1998
Scheduled Location: The Science Hall in the Science Museum, Kitanomaru Park, Tokyo.

"School Children's Idea of Micromachines"

Ms. Ayako Mochizuki
Teacher, Okubo Municipal Elementary School,
Narashino, Chiba Prefecture

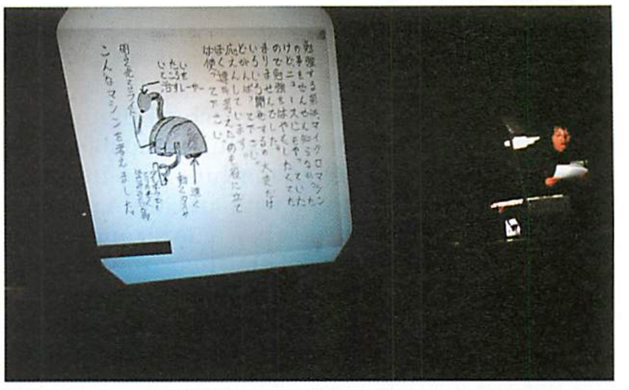
Every day I talk to six- and seven-year-old children, so I am a little nervous standing here, speaking to an older audience.

While waiting my turn to speak, I watched other peoples' lectures on a monitor, and was struck by their highly technical contents. I am a complete outsider to the subject of micromachines, but the micromachines that I intend to talk about today are the ideas of 10-year-olds, who I believe are a little more flexible in their thinking than those of us here today, so I hope you will find my lecture interesting.

Many of us are bewildered by the remarkable changes that have taken place around us in the past few years. In the adult world, many kinds of machines have entered our lives, both at home and at work, and although they are very convenient, they often cause us anxiety. In the world of children, similar phenomena can be seen. Computers and TV games have entered their lives, but children adapt far more easily to machines than do adults. To the children, these machines are merely toys. Children also recognize the convenience of machines, and they are interested in pursuing them further. You would be amazed at the level of skill they display in TV and computer games. As part of the school curriculum, computers are now being used in classrooms. Computers are used to draw charts and review lessons, and are used as word processors to write compositions. So as you can see, the technology of the future is beginning to make its presence even in the children's world.

Nowdays children can obtain the same kind of information available to adults through their textbooks, mass media such as the television, children's books and so on.

Of these, when considering books and other materials for children, compared with before, when stories such as fables and children's tales were numerous, the number of articles of the genre referred to as explanatory writing has greatly increased. Furthermore, the areas covered in this explanatory writing have also been displaying change. Once, the topics were "insects, mammals, and fishes", which were written on as real things that children could feel close to, and which by pursuing their reading children could use to make full use of the experiences that they themselves had cultivated. But among the educational writing used today, a number of articles thought to aim at "the future" and "environmental problems", as exemplified by *"Uchuu-sen Chikyuu-gou"* ("Spaceship Earth" in English), written by Takashi TACHIBANA, are in evidence. "The Dreams of Micromachines" by Professor Naomasa Nakajima (The University of Tokyo), which is included in fourth-grade textbooks, is no exception. In fact,



"The Dreams of Micromachines" appeared in a new textbook only recently. The children show great interest in this subject, because it is something with which they are almost totally unfamiliar. For the children, it is a subject that is outside of everyday life, something that they have never before experienced. They know that the micromachines exist, however, and they are fascinated with them. The children are interested in learning about what they can do, what uses they are put to today, what they are expected to be able to do in the future, how much progress is being made in research, and so on. It arouses the children's curiosity. And then, using the knowledge they have gained in the classroom and their own imaginations, the children actually began to invent their own micromachines.

The children expressed their gratitude in writing to Professor Naomasa Nakajima for sending them a micro-robot, and I would like to read some of what they wrote: "I like to make things, so in the future I would like to make micromachines with Professor Nakajima." Another child writes, "I have come up with this micromachine. I hope you can make use of it." Each child expresses his or her feelings about the experience. Technically speaking, some of the ideas are obviously far from realistic, but they are original, coming as they do from the children's imagination, and they are ideas that could only have come from young, flexible minds. That is the kind of micromachine I would like to talk about today.

As I said, based on the information they acquired in class and through research conducted on their own, the children used their imagination to invent their own micromachines. They focused on two main points: "convenience" and "compactness." For our purposes, a convenient micromachine was one that can perform multiple tasks; to achieve this, many tools had to be added. This definition was based on the notion that a robot that can perform multiple tasks is practical, as we have applied the same concept to the micromachine.

As for the quest for a compact machine, the children described the size as, "small enough to rest on one's shoulder," or "a diameter of 5 mm," which also shows that the children have grasped the meaning of "micro." In terms of technique and ability, they are of course amateurs, but with their powerful imaginations and strong desire to create something, they have come up with original ideas reflecting what they have learned from both their positive and negative experiences with the subject. I would like to show you some pictures that they created.

This is a picture of a micromachine that can be injected into a blood vessel; these extendable arms carry medicine. This micromachine was invented in the hope of curing illness without causing pain.

The next picture is also a micromachine designed to cure illness. This "teardrop-shaped" micromachine is equipped with a wide array of instruments to enable almost any illness to be cured easily. In addition, to relieve pets of ticks and fleas, a micromachine acting as an exterminator was invented.

The children also thought about the need for micromachines for cleaning. All skyscrapers have windows, all of which must be cleaned. This small vacuum cleaner for windows, operated by solar power, would not spoil the appearance of skyscrapers as exterior cleaning devices do, and could be employed according to the window size and the cleaning frequency. This concept can be extended to things other than skyscrapers, and the micromachine can also be used to clean the glass of water tanks used in aquariums.

The children had difficulty grasping the notion of repair, as they live in a world filled with disposable goods, but by taking into account the possibility of a breakdown, they realized that micromachines must be repaired by other micromachines, and they stressed this point. Children today spend much of their time alone, so when they have a problem, they look to micromachines for help. Children play with micromachines, study with them, live with them, spend time with them, and turn to them in times of need. In other words, micromachines are the "otasuke-man," a kind of a helper.

The children saw the need for micromachines that are more useful for adults in their daily lives. In recent years, women have become very active in the business world, and of course the closest female figure for most children is their mother. Although the working hours of some mothers may be restricted, an increasing number of mothers are working today. As the children grow up seeing their mothers work, they become used to the idea of working mothers and long to follow in their footsteps. When they begin to understand the need to balance home life and work, it is natural that they will also see the need to rely on micromachines for support.

The above work was carried out during the 1995 and 1996 academic years. Okubo Higashi Elementary School, where this learning took place, is a pilot school for the Japanese language, and the educational piece "The Dreams of Micromachines" was taken up as part of that research. In the same way as the children, the teachers were in a state of near ignorance. Firstly, we did not have a concrete image of micromachines, and solving this problem had to be the first priority. This was the first step in children's starting to come to grips with micromachines, but was also the most uncertain. Subsequently, children were drawn in by the article, began to understand micromachines, had their knowledge increased, and began to think about their own creations.

Along with considering the creation of micromachines, the children thought about motive power. The reason for this would be their study of photoelectric cells in science class, and in their own way, children though about such matters as how micromachines would move, and what power source could be used. Medical micromachines could be used to find foci and defects, cleaning machines could be used to pick up dust and grime; despite this being an unknown world, children had many good ideas. And with regard to convenience of operation, drawing on machines they had actually used, children built in controllers and monitors.

Lastly, I would like to say that the children greatly look forward to the realization of micromachines. Their expectations are much stronger than those of adults, as their ideas may actually be realized in the future. However, they also have some warnings to give: "If they are actualized, we will come to depend completely on micromachines. Curing illness is a good thing, but if we let a machine do all our laundry, we would become lazy. We should do some of the work ourselves." Even as children, they have anxieties about the future.

And now, I have a request for you researchers in the audience. As I have said, based only on what they learned in class, the children, with their flexible minds, came up with their own ideas for micromachines. However, there is currently little accurate information on micromachines for children. The data available at present is insufficient for children to fully understand micromachines. If materials targeted at youngsters become available, not only for the elementary school children but also for junior high school pupils, who are at an impressionable age, the children will certainly show an interest in them. I would like to ask for your cooperation in providing more information on micromachines, for the benefit of these children and those who follow them. If the children can be provided with up-to-date information, I am sure that we will see further progress in this field.

The possibilities lie ahead of these youngsters are unimaginable, but it is clear that micromachines will be of great service in the field of medical treatment, the world of industry, and in everyone's lives in innumerable ways. In the future, when these youngsters reach the point at which they begin to operate these micromachines, they will have new ambitions. I sincerely hope that you will support them so that they will have the opportunity to take part in realizing the micromachines of the future.

"Micromachining as a Culture"

Dr. Masaki Ukai
Lecturer, Kyoto Bunkyo University

Let me begin by admitting that when I accepted the honor of speaking during the session "Thinking of Micromachine", I knew almost nothing about micromachines. I read the assortment of documents that the Micromachine Center sent me, and also went and looked around the Exhibition "Micromachine '97" today. Even so, I still am not quite sure what these things are. So it is as an expert in cultural anthropology, and a micromachine novice, that I dare to spread my wings and speak today.

One definition of a micromachine is "a minute device (of less than a few millimeters) composed of highly sophisticated functional elements, and used to perform minute and complicated tasks." Putting this in my own plain terms, I'll just say they are "really small machines." This is my understanding – or misunderstanding – and from it, I have formed a few fancies, and in some cases, delusions. These are what I would like to share with you today.

First off, micromachines make me think of the stories about little people – the "Tales of Dwarves" – found in Japanese folklore. These stories are about various characters – *Issun-Boshi* (Tom Thumb in English), *Oyayubi Taro* (Thumb-sized *Taro*), etc. – who have special abilities due to their small size.

There is one story in particular from this genre that I would like to introduce here. In the Mogami area of Yamagata Prefecture, Japan, the story is told of *Gobu Jiro* (Gobu means half an inch.). Long ago, in a certain village, there was an old couple without children. One day, the old wife's thumb began suddenly to hurt and swell, and before long, the flesh there opened to give birth to an infant boy. Since the baby was born from a thumb, he was tiny, measuring about half an inch. So the old couple named the baby boy *Gobu Jiro*, and they cherished him. One day, *Jiro* rode out into the sea in a boat made from the leaf of a tree. The boat was taken by the wind to another village, and *Jiro* wound up staying in the home of an old woman. When night came, the old woman told *Jiro*, "Every night, a monster appears in the village, gobbling up the villagers." That night, the monster did show up, and began sniffing around, searching for villagers. Because of the monster's great size, *Gobu Jiro* was sucked right up the monster's nose as it snorted, and entered its body. Using the pin he carried in place of a sword, *Jiro* promptly lanced the beast from the inside, killing it. As the story goes, after subduing the monster in this manner, *Jiro* became the son-in-law of a wealthy villager. Stories like this, in which little people with special abilities achieve happiness, are told all across Japan. For example, there is the story of *Issun-Boshi*, in which through a stroke of luck, the tiny boy becomes the size of a normal man and lives happily ever after. But there are many similar stories of people, like *Jiro*, who achieve happiness even while remaining small.

Just in passing, I wonder how our human world looks when seen from *Gobu Jiro*'s point of view. Unfortunately, there seem to be no Japanese fairy tales that cover this theme. Instead, let's consider the well-known "Gulliver's Travels." As you know, Gulliver went first to Lilliput, a land of little people, and then to Brobdingnag, a country of giants. Here's a passage from the story where everything around Gulliver is of great size:

"I fell into a high road, for so I took it to be, though it served to the inhabitants only as a footpath through a field of barley. Here I walked on for some time, but could see little on either side, it being now near harvest, and the corn rising at least forty feet."

Forty feet, so about 12 meters...

"I was an hour walking to the end of this field, which was fenced in with a hedge of at least one hundred and twenty feet high, and the trees so lofty that I could make no computation of their altitude."

It is also interesting to note that when viewed on a larger scale, things we hold to be quite normal reveal their imperfections. For example, another passage from the book is about a woman's breast, and reads:

"I must confess no object ever disgusted me so much as the sight of her monstrous breast, which I cannot tell what to compare with, so as to give the curious reader an idea of its bulk, shape and color. It stood prominent six feet, and could not be less than sixteen feet in circumference. The nipple was about half the size of my head, and the hue both of that and the dug so varied with spots, pimples and freckles, that nothing could appear more nauseous."

Tiny person that he was, Gulliver became a showpiece in this country of giants, and the king treasured him. I think that, for little people, the world must look a good deal as Gulliver described it above.

Now, I would like to change the topic a bit. Micromachines are one kind of machines. What impression do we humans have of machines? For we humans, do we see machines as belonging more to Lilliput, the world of little people, or to Brobdingnag, the world of giants? I would have to say we tend to see machines as Brobdingnagian; that is, machines are thought to overshadow or tower above us. Machines have come to be seen as things that surpass human abilities, being stronger, faster, bigger, or whatever.

Micromachines are just the opposite. As I picture life with micromachines, I expect that we may feel something like Gulliver in Lilliput.

We often hear that technology has changed humanity. So how might micromachines change us? I can say with confidence that micromachines may offer us a way to view things "from the inside." Until now, the human race has viewed frontiers as "external." From our hunter-gatherer existence through agricultural development to the era of space exploration, we have sought to "open up" "our external world." This can be attributed to our innate desire for self-expansion.

Micromachines, however, lead us in the opposite direction, that of self-reduction, by allowing us to carry out various tasks inside pipes, inside machines or even inside the human body. In this sense, micromachines offer us the "internal" perspective. Gaining such a perspective could potentially destroy the balance that has been preserved when our insides were concealed from us. For instance, I would expect that there are few patients who would not be badly shaken if a micromachine displays a thick layer of cholesterol in his veins. Imagine that there were "cholesterol-cleaning micromachines" that could scrape down the blood vessel and restore it to good health; this surely is the ultimate mechanical approach to the human body, and it is slightly unsettling. Perhaps it is better not to know these things at all. Yet through micromachines we will surely be discovering more and more about our insides in the future.

Whether this is sufficient to change humanity or not is another question. We already know a great deal about, say, the human body, from our internal organs and skeleton to our cells and genes. The micromachine, therefore, can only reconfirm our existing knowledge of the human body. Furthermore, since we view everything visually through our eyes (even the inside of the human body), the process itself represents little more than an external rendering of the internal world.

I believe that micromachines will open up senses other than the visual to us. For instance, when a micromachine is moving along inside a vein, is the sensation painful, itchy, ticklish, or even pleasurable, and what noise does the engine seem to make? If a micromachine were implanted in our bodies, would we feel like we were under the control of that machine? Or would we feel as though the machine were living within us, even as something like a pet? Would we feel as if the machine were a part of us, or as though it were something foreign? It is conceivable that micromachines could be used to excite or enhance our non-visual senses, such as touch and hearing, and even taste and smell. In this age of inflated emphasis on the visual, it could be that micromachines give us a chance to restore a feeling of alignment among the five senses.

This said, after having a look around the exhibition "Micromachine '97" here, I must say that micromachines are very difficult for us novices to understand. Micromachine is a field that the novice may tend to understand in a "black-box" fashion. And this, I think, can be a source of great danger.

We novices have at best limited contact with, and understanding of, all the tools used in highly specialized fields. Before we know it, however, these tools may spread rapidly into use all around us. This phenomenon invariably gives rise to a sense of unease. Furthermore, if only a single group of specialists have the knowledge needed to operate some tools, it becomes dangerous for anyone else to attempt to do so. Then again, there are examples of machines that, once mastered by novices, go on to see widespread use in unexpected ways. One recent example is the so-called "pocket-bell" pager. After new features were added, these pagers experienced an explosive upsurge in usage, particularly among Japanese high-school girls. To the uninitiated, few things are more important in a new technology than ease of mastery and the opportunity for convenient daily use. In fact, these needs present an opportunity for developers of new technologies.

One word seems of particular relevance here. That word is "cute." Nowadays, this word is used so often in Japan that it can be said to embody, in some sense, the current Japanese conception of beauty. It has a "sweet" connotation, and is used to mean everything from small, to childish, innocent, or round. The word "cute" can thus be applied rather aptly to micromachines, at least in terms of their small size. But what about their other aspects? On balance, the dominant features of micromachines seem to be their exquisite design and use of high technology; here, the word "cute" does not apply. Stilted words are often used to describe micromachines. Of course, in one sense, micromachines just need to function well. Some might say, well then, who cares if they are cute or not? But such an attitude only leads the layperson to see micromachines and their associated technologies as mysterious "black boxes." And once that happens, micromachines will unavoidably become a source of fear to the uninitiated. For this reason, it is my hope that micromachines will be presented and developed in an adequately "cute" way.

I began by making some comments on the "Little People" of fairy tales. I would propose that that micromachines are the little people of machines. In folklore, the little people bring good fortune, and my hope is that as the little people of machines, the micromachines live up to this tradition. I also hope that we humans do not find ourselves in the same situation as Gulliver, as described in the famous opening verse about his trip to Lilliput, which goes, "When I awoke, I was bound by ropes to my bed."

"Socio-Cultural Implication of Micromachine Technology"

Shin-ichi Takemura
Associate Professor, Tohoku University of Art and Design

My field is cultural anthropology, and like the two who have lectured before me, I am an outsider when it comes to micromachines. However, from the standpoint of anthropology and human studies, I have had a particular interest in how technology affects our culture, our way of living, and our society. Recent trends in technology, and in the areas of life sciences, genetic diagnosis, etc., pose important problems for all of us in anthropology. After hearing the lectures today, I think that the proposals we have heard in the fields of micromachines and nanotechnology, are already having, and will continue to have, a great impact both on our fundamental sense of humanity and on our view of the world. Appropriately, I thought, one speaker noted that, "We must further study humans." Now more than ever, we anthropologists feel that as we consider these current problems, we must begin to think about how human behavior interfaces with the cutting edge of technology.

Based on this perspective, I would like to offer three problematic topics for consideration today.

The first is the great change in our fundamental views of humanity and life.

The second is related to the existence of a new sensitivity, due to our new freedom to see the world across a relatively wide-ranging scale, from the micro to the macro.

The third is related to the possibility of a fundamental paradigm shift in contemporary scientific technology.

My basis for this concept is the notion that, as I put it, we continually confront a paradox of continuity and discontinuity.

Each of these topics represents an extremely difficult problem. I have taken the fact that I was invited to this session, and was able to understand the presentations, to mean that I should at least outline these topics from the standpoint of the layperson, or the culturally inclined listener. So this is the perspective that I will adopt in my remarks today.

First, with regard to the shift in our views of humanity and life, one of the most interesting and influential things about micromachines and nanotechnology is that by working on a microscopic scale, they are able to give us a viewpoint that goes beyond our traditional dualistic views on, for instance, nature and the man-made, machinery and life, analog and digital, etc. That is to say, micromachines may be in the process of creating continuous planes that

describe each of these pairs. If we take a cell, or a ribosome, one of the cell's essential organs, to be a nanomachine programmed by a tape of molecules such as RNA, then we are on our way to creating a paradigm in which the engineered agents which so many of you are striving for, and the living structural elements that make up our cells, can be expressed on one continuum. There is a very notable trend today toward researching the cells as if they were bio-computers. And from the standpoint of an outsider, it is interesting, too, to look upon research trends like using enzymes as a form of molecule assembly, or flagellum motors. Here on these levels as well, I am greatly impressed to see that machines and living things are increasingly being understood on an integrated plane.

At the same time, I think it is important now not only to see life as bio-machines, but also to see the converse, that man-made machines can be forms of life, or applications of life. In his special discourse today, "Micromachining Technology and Biosensors", Professor Karube talked about "sensor-equipped micromachines that navigate the blood vessels," thereby automatically controlling the physical condition of diabetic patients. Then, Dr. Tao, in his lecture "Expectation to Micromachine Technology for Global Environment Protection," spoke of spreading microscopic global sensors across the face of the Earth, so that instead of taking sample data from observation points and analyzing it, a worldwide network could be used to provide data collection, collation, and on-site analysis. When things of this nature are actually produced, we will enter a new plane that differs from our conventional view of the world.

One very interesting thing to note here is that until now, human technology, whether it was used to exploit "nature" or to process "materials", has actually set out to separate humans from the natural environment, and to create an isolated man-made space, even though it operates on a relatively human-sized scale (and in that sense operates in a continuous plane). Though it operates in this continuum, then, human technology sets out to create a non-continuous region. As a result, within the natural realm, the human realm has had a foreign-ness, an alien-ness, that has in fact created a non-continuous region. Nano- and micromachine technology, on the other hand, pass from the human-sized level of the everyday and approach an extraordinary, non-continuous microscopic dimension that people can not touch, a dimension that they can not see. However, by virtue of their descent to this level, micromachines can bring a single continuity to our natural and artificial worlds, and to a future world in which micromachines play a natural role. By dropping down to the non-continuous level, then, they actually create a new continuum. For example, one can foresee the possibility that in place of the kind of machines run by large gasoline engines, which have an essentially foreign and destructive nature, more elegant, energy-efficient, and ecological micromachines will gracefully take their place in the natural environment and in the bodies of living things, creating a seamless continuity.

In terms of mankind's technological culture, in a sense, these new developments represent a complete reversal of the direction in which a part of technology had been moving. The world's ecosystem now faces great threats, especially at the microscopic and atomic levels, due to nuclear technology and its extraordinary explosive power. At the same time, when we descend to the atomic/molecular level, we now have the possibility of creating a continuity between human and natural spaces. I think that this represents an epoch-making development. And when looking at this possibility, there is naturally a part of me that wants to look upon it very positively. But it is also possible that from this continuity, a new discontinuity will be derived. To be more specific, consider the term "post-human," which one now hears used to describe a type of hybridization between humans and machines, or a living being with an imbedded drug delivery system (DDS). It is possible that a new "post-human"-type reality will be created that moves us away from modern life and humanity as we know them.

Consider the following example: The racing machines used in today's F1 car races are tuned by teams of skilled mechanics. In today's Olympics, however, where success depends on your own body, such a notion would be absurd. Henceforth, though, as people begin to live with DDSs and other internal machines as a matter of course, it is likely that delicate tuning of those machines may augment our physical powers, enabling us even to compete in the Olympics. And if things turn out this way, won't we gradually reach a plane where it is difficult to differentiate between an F1 car race and the Olympics? Hypothetically, we may even see the day, sometime in the twenty-first century, when F1 car races and the Olympics merge. I would expect that most of us react with repulsion, or denounce the inhumanity of such ideas, when we hear about them. But should we? Upon closer examination, the glasses that we use every day are an extension of our eyes. In the same dimension that we live as flesh and blood, we are able to casually wear glasses and augment our eyes. The internal hearing aids now coming into increasing use move the process further along, and closer to the insides of our bodies. With additional progress and development, we will be able to create a micro-biomachine that tunes the physical condition of a diabetic patient, or a bio-chip that moves around the inside our bodies. At this point, will people with such devices embedded in their bodies be barred from competing in the Olympics? Hardly, I would guess. And if we do reach such a point, I expect that many other distinctions that we now take for granted, just like, "The Olympics are about human competition, F1 is about mechanical competition", will have to be abandoned or reconsidered.

Lynn Margulies, a scholar famous for her work in the theory of symbiotic evolution, says that each cell is a computer. The component parts were not constructed from the outset with the purpose of building a computer; rather, they were formed for a variety of reasons, and at some point came together under a single concept to form a computer. She says that billions of years ago, aerobic bacteria began to evolve symbiotically with cells that had larger membranes, and eventually developed into the aerobic cells that we now see, with their nuclei and cell membranes. Thinking along these lines, the history of evolution of life on Earth contains a history of symbiotic evolution as well, in which completely separate parts come together to form a new continuity.

Following this logic, I submit that the birth of a new realm of living things, or a new realm of humanity, based on symbiosis with a biochip micromachine (= mechanical environment), is far from something that could be called "unnatural", or "inhuman." Even if we do feel an emotional aspect of disgust, far be it from us, given our vantage point over the history of life and mankind, to call such a development unnatural or inhuman. Rather, if we do use such emotional labels, then perhaps it could be said that it is our sense of nature and of mankind which is too limited.

Even so, there is a great flaw in the preceding story. Even though micromachines are based upon a rational extension of life and natural histories, it is a fact that at least one type of discontinuity will result.

Nor is that all. Biochips, DNA (where research is now underway in which it is modeled as the element of life), and protein, are all vulnerable to heat, and in various other ways have shortcomings particular to living things. There is the possibility that our lives will move into another dimension when our human flesh and blood is brought together with living machines built around a different basic element, one which has the strengths particular to living things, but not the characteristic weaknesses.

Today's talk is not at the level what will happen in the next three or five years, but rather the next thirty or fifty. However, at the very least, from the standpoint of the anthropologist or student of humanity, the revolution is now beginning. When the DDSs and micromachines discussed in Professor Karube's lecture are employed as a treatment for diabetic patients, they will actually become more than a remedy for diabetics — they may also be used to enhance the performance of Olympic athletes. We can already see clearly the possibility that micromachines will become a partner which normal people will employ in a form of symbiotic evolution.

It is evident, then, that we are entering an era in which we see the essence of life at a new depth, thanks to nanotechnology and micromachine research. The research that all of you are doing is one important vehicle for self-cognizance of both life and the world. However, insofar as self-cognizance is accompanied by self-transcendence, even if life as we have known it is not negated, nanotechnology and micromachines may at least cause it to be pushed to another plane. On further examination, mankind may still be living a transitional existence. Far from being at the peak of our advancement, we may be quite some distance from any consummate realization of mankind's potential with the natural world. And by considering our current existence as nothing more than one stopping-point along a long process, I think that at the very least, a great paradox of continuity and discontinuity becomes quite evident.

And so on to the second issue, that of scaling. This represents another revolutionary viewpoint. We have been looking at things with microscopes, and enlarging and viewing the planets through celestial telescopes since the seventeenth century. Today, though, we have the freedom to conceive of two different realities to view heavenly bodies and microbes as being part of one freely scalable whole. For example, we now face problems with the global environment. From the viewpoint of a microbe, however, our bodies are an environment unto themselves. Therefore, our environment is not only within us, but also outside of us. I believe that objective scaling of this type brings about new perceptions. In the same way, as in the analogy I offered earlier, our bodies and cells are like a computer made up of many individual functional parts. We could also say that we are a pluralistic, symbiotic society made up of a variety of microbes. If we understand our bodies in the same way, the same analogy can be applied to this Earth. In other words, though each of us look like individual entities, maybe we humans are simply one kind of mitochondria. This is just an analogy, but in our mitochondria-like existence, perhaps we will become complete by joining with a larger, super-organic entity, or perhaps we are only one part of a symbiotically evolving whole. Changes in perception of this type are not simply a matter of scaling, of course. At a microscopic level, surface tension and viscosity become more important than gravity. Factors such as thermal vibration, etc. change depending on their scaling. One very important point is that by moving back and forth along this pluralistic scale, we achieve the freedom to see the world in new ways, and this is very important.

On the third point, which concerns recent scientific technology itself, I have no answer. Rather, I would like to pose a question to all of you. As I have said, our human existence takes place within a pluralistic society made up of individuals. The word "individual" itself refers to the fact that a person cannot be divided. Looking at a single being from a modern view of life, however, we see that it is not an individual, really, but a "dividual." That is, a being made up of multiple things, and capable of being divided indefinitely. Expanding upon this viewpoint, the multiplicity that comprises us, functionally, is not an altogether rational thing. For example, what we see in the disease AIDS, in the problem of its reverse transcriptase and retrovirus, in addition to the obvious fact that the retrovirus causes a dangerous and fearful disease, is also something positive, i.e., the genetic information that the reverse transcription gives us leads to evolution and opportunity, at least from a sufficiently long perspective. Our accumulation in this way of many reverse-transcribed things — sometimes called junk DNA, etc. — could be called an enormous waste. The scholar Freeman Dyson has referred to this as "permissible error." It is at this level, when we look from a perspective of pluralism with waste, that I believe we will begin to see the limits of the elemental reductionist idea, or mechanical approach, of taking parts prepared in our historical elementalist way, and assembling them into rational machines. Even if we do not go so far as to use the term "permissible error," it is certainly not true that genes are a perfect component made up neatly of only what is rationally necessary. The fact is that not only the genes, but the human essence as well, contain elements that deviate from the lines implied by mechanistic and elementalist thinking. This being the case, I propose — not negatively, but in a spirit of anxious anticipation — that micromachine research must progress in a direction that enables it to naturally shatter modern mechanistic thinking from the inside.

Exhibition "Micromachine '97" Held

Exhibition "Micromachine '97" was held in success on three consecutive days from October 29 through 31, 1997 at the Science Museum of Kitanomaru Park, Tokyo, together with the 3rd International Micromachine Symposium.

The exhibitors, including Micromachine Center and 21 supporting members of MMC, comprised enterprises, non-profit organizations, colleges and universities, and research institutes from Japan and abroad. The total number of exhibitors was 70, which was the largest ever. The greatest scale exhibition of micromachines in Asia, where the latest technologies and research results about micromachines are demonstrated, is ever-growing both in scale and contents.

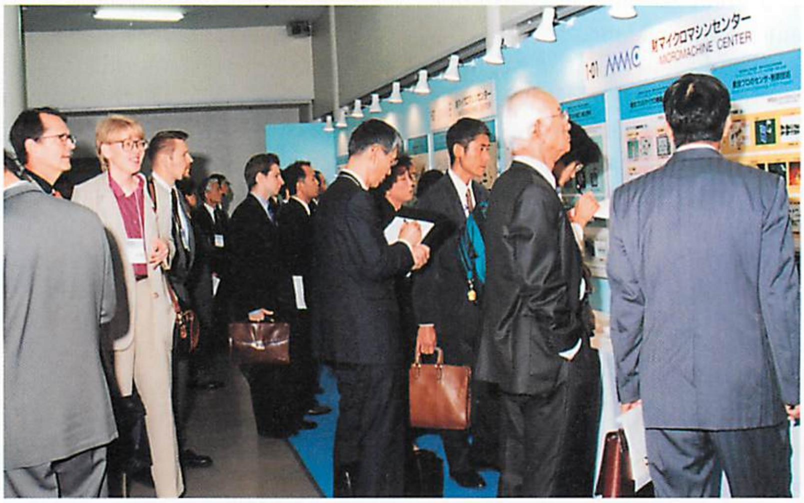
Major exhibition items were micromachines, micromachine components and application systems, MEMS related systems, molecular machine related technologies, micromachine manufacturing related equipment and materials, and micromachine evaluation technologies and equipment. The contents are growing richer every year, to make the event an exhibition for experts engaged in R&D, technology, design, production and manufacturing, and operation and management. They encompass every industry from machinery and precision instruments through electronic and electric appliances, medical treatment, information and communication, automobiles and transportation, biology, physics, chemistry, construction, steel making, aviation and space, to ships and ocean development. For businesses engaged in R&D of micromachines, the exhibition offers an occasion to publicize their technology, equipment, and products. For academic and research institutes, it is a chance to promote their research results public. For newcomer businesses, it is a chance to promote their products and technology.

On the last day, October 31, Katsusada Hirose, Director-General, Machinery and Information Industries Bureau, MITI, and Dr. Takeo Sato, Director-General, Agency of Industrial Science and Technology, MITI, took the time to make a careful inspection, in spite of their busy schedules. In the three days, a total of about 3,300 inspectors visited the exhibition.

The event was reported by the media. Business Line, an evening satellite broadcast TV program on BS1, NHK, introduced the micromachine exhibition on October 31, under the subtitle of "industrial technologies for the next generation," and reported on some results of "R&D of Micromachine Technology", the Industrial Science and Technology Frontier Program of MITI.

Schedule of next Micromachine Exhibition

Period: October 28 (Wed.) to 30 (Fri.), 1998
Place: Science Museum, Kitanomaru Park, Tokyo
Inquiry: MESAGO Japan
Tel: (081) 3-3359-0894
Fax: (081) 3-3359-9328
E-mail: KYP03300@niftyserve.or.jp
URL: http://www.mesago-jp.com



Exhibition full of inspectors

The World's First Standardization International Workshop Held

At micromachine summits and on other occasions, Micromachine Center (MMC) has publicized the importance of standardization for the growth of micromachine technology. At the Third Micromachine Summit held in Canada in April 1997, countries reached an agreement to hold a first standardization international workshop. In consequence, MMC held Micromachine Standardization International Workshop Tokyo '97 at Tokyo YMCA Hotel on October 28, 1997.

MMC invited Mr. Kiyoshi Honma of Machinery Standards Division, Standards Department, AIST, MITI, and Mr. Noriaki Ozawa from Industrial Machinery Division, Machinery and Information Industries Bureau, MITI, as guests. Prof. Hisayoshi Sato, Chuo University who works also as a chairman of the Micromachine Standardization Committee presided over the workshop. The meeting began with the guest speech by Mr. Honma. Participants from the various countries and region and the contents of their speeches are listed below.

- Standardization on micromachine technology
  Takayuki Hirano (Executive Director, MMC)
  Report of research and study in Japan
- Technical terms
  Prof. Nobuyuki Moronuki (Tokyo Metropolitan University, WG chief member of the Committee on Micromachine Standardization)
- Methods of measurement and evaluation
  Prof. Kimiyuki Mitsui (Keio University, WG chief member of the Committee on Micromachine Standardization)
  Report of standardization activities in countries and regions (in alphabetical order by country or region)
- Australia
  Prof. Ian Bates (Royal Melbourne Institute of Technology)
- China
  Prof. Yihua Yang (Tsinghua University)
- Finland
  Mika Saikku (The Finnish School of Watchmaking)
- France, EU/NEXUS
  Gaëtan Menozzi (Sextant Avionique, chairman of NEXUS)
- Taiwan
  Prof. Jin-Shown Shie (National Chiao Tung University)
- The United Kingdom, IEC
  Prof. Howard Dorey (Imperial College of Science)

After these reports, active discussion was done by all the participants including the Standardization Committee and the Study Committee on Micromachine Standardization of MMC. Chairman Sato, at the end summed up the discussion as described in the following, and the standardization international workshop with 16 participants (including observers, the total member was about 30) closed

in success. At the party held after the discussion, members gathered with participants from overseas, and talked informally and frankly, about the future of standardization.

Chairman's summary

1. The standardization is one of important factors in micromachine development. In the international area, IEC started a work from the semiconductor device base. It is anticipated that wider approach is necessary to multidisciplinary micromachine. This workshop was intended to discuss future course of micromachine standardization.
2. The workshop proceeded with presentations on implication of micromachine standardization, Japanese study reports of terminology and measurement methods and activity reports on IEC and participating countries/regions.
3. After the presentations, the participants discussed a possible future course of micromachine standardization. It is general feeling among the participants that IEC work is hopeful and expected to expand its work scope and also in parallel to IEC, until the build-up of an international standardization structure on a full scale, an International Working Group or Network would be helpful to make progress international standardization, especially terminology.
4. The workshop anticipated the next gathering will be organized in coincident with the coming Micromachine Summit in Melbourne in April, 1998. And the outcome of this workshop will be reported to the Summit for further discussions and cooperation.

Research on possible applications of micromachines in life style of 21st century —Report from Europe—

As a part of the project to research possible applications of micromachines in the life style of the 21st century, a team of researchers was dispatched to Europe from November 16 to 23 to survey the European life style and trends of development of micromachine related technology. The team consisted of seven people: Associate Prof. Tetsuo Kidokoro, Department of Urban Engineering, The University of Tokyo, who is a chief member of the survey and research committee working group; Research Associate Tuneo Chinzei, Faculty of Medicine, The University of Tokyo; two from supporting member companies; and three from MMC.

• Survey of European life style

The team visited the Economics Laboratory of Ecole Polytechnique (France), Regional Planning Department of Royal Institute of Technology (Sweden), and City and Regional Planning Department of University of Wales (U.K.) where they received lectures from experts. People in all the places visited showed interest in micromachine technology and lectured willingly. They spoke mainly about the characteristics and problems of the society and cities that embrace life style, and extended to a meaningful point of whether micromachine technology and industry can play a part in solving the problems.

Major topics in France were the aging society and social integration among generations, and privacy. In Sweden, they focused on Intelligent Transport System, which is an important urban policy item. In the U.K., competitiveness and sustainability of the market and forms of labor induced by regional development were the subjects.

The mission also visited Stockholm Center for Technical Aids in Sweden, to survey welfare equipment.

• Survey of development trend of micromachine related technology

The mission surveyed trends in the development of Micro-electro-mechanical systems (MEMS) technology at Royal Institute of Technology and University of Wales, and joined the colloquium of Recent Advances in Micromachining Techniques held in London by the Institution of Electrical Engineers (IEE) to survey trends of recent micromachining technology.

At Royal Institute of Technology, researchers are energetically applying MEMS technology to develop instruments such as fluid density meters, pressure sensors, and valveless flow pumps for automobiles and medical use. Their specialties are advanced devices such as the three-dimensional hot-wire anemometer made by lifting a silicon structure that exploits the thermal contraction effect of polymer coating, and cost reduction of devices such as replacement of micro pump materials with plastics.

At University of Wales, researchers study biochemical experiment modules. They develop small experiment modules that integrate pH sensors and glucose sensors to reproduce various chemical and biological reactions that take place in the microgravity environment of space shuttles or satellites. That gave an impression that it would not be long before micromachine technology will be utilized in outer space.

With the MEMS and bio-engineers, the mission team held free discussions about sustainable life style. One unique idea was the home farm, an integrated system for growth control and waste treatment by biotechnology coupled with sensor technology that enables farms in each household and reduces environmental burden incurred by transportation of farm products. It can be exciting to search for possible micromachine applications through active contact with the ideas of bio-engineers.

Free discussion at the laboratory of Dr. Barrow (right) in University of Wales

About the time of the IEE colloquium, Executive Director Hirano presented a guest research under the title of "Micromachines; Past, Present and Future" and answered questions about technologies and policies. The future-oriented enlightenment activities by expressing the future of micromachines by imagination of kids, the coming generation, was highly evaluated.

This research in Europe gained for us profound knowledge of part of the micromachine research there, and reminds us that for true acceptance of micromachine technology in the society, not only the necessity of the technology but also the cultural climate of the land and regional policies must be taken into consideration.

MITSUBISHI ELECTRIC CORPORATION

Tamotsu Nomakuchi
Managing Director, Chief of Development Division

1. Engagement in micromachine technology

Recently, people are increasingly conscious of environmental issues. Since MITSUBISHI ELECTRIC CORPORATION started development of micromachine technology in the early 1990s, we have been aiming at human-friendly, earth-friendly, unobtrusive machines. Machines that take over the demanding work of people, that do not waste energy and resources during manufacturing operations, and that get jobs done without people even realizing it. Those are our ideal machines. Through participation in the Industrial Science and Technology Frontier Program of MITI, we are promoting research and development with high hopes.

2. Development of micromachine technology

In the Industrial Science and Technology Frontier Program, Mitsubishi Electric is tackling R&D of chain-type micromachine for inspection on outer surface of tubes. The system consists of multiple unit machines each of which has a body measuring mere 125 mm^3, or 10 mm in width if connectors are included. Those units enclose the target tube and move up and down to check for flaws. For this system we developed two systematization technologies. One is the block assembly technique. In the conventional assembly of micro parts, manipulators capable of precision positioning were popular. Instead of this, we proposed a new concept of assembly that positions and connects parts exploiting magnetic polarity and attraction. (See Fig. 1.) By this method, after micro parts are neighbored roughly, they are automatically pulled together and assembled by magnetic force.

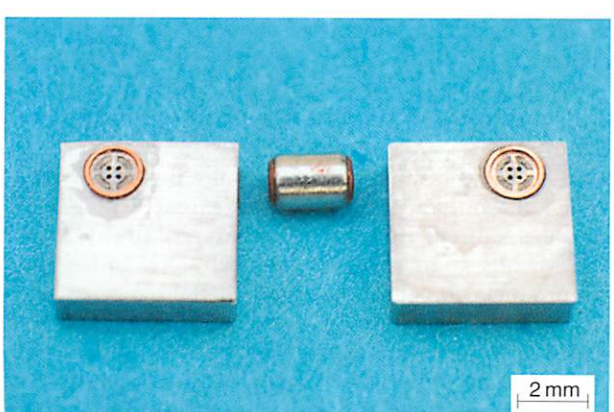


Fig. 1 Block assembly parts

Another systematization technology is the motor function simulator that runs the unit machine. Development of conventional micromachines often involved repeated processes of prototyping, performance evaluation, and improvement. Our simulator (Fig. 2) dynamically analyzes the motion of a micromachine on wheels. Immediate solutions are given for such problems as the effect of the friction factor between the driving and driven wheels upon gyrating performance of the micromachine. By using this simulator, fewer prototypes, and less labor and resources will be required, and total development efficiency will be improved.

Fig. 2 Simulator display

In the development of micromachines, apart from such systematization technologies, individual fundamental technologies are indispensable. We also develop high torque micro motors as a part of device development.

3. Future plans

We at Mitsubishi Electric are continuing our efforts in well-balanced development of systematization technologies and fundamental technologies to realize the ideal machines that I mentioned in the beginning. We will continue research and development to contribute to the society through development of practical micromachine systems, as well as to promote the Industrial Science and Technology Frontier Program.

Interview with Chairman Menozzi of NEXUS committee visiting Japan

Mr. Gaëtan Menozzi of Sextant Avionique who chairs the NEXUS committee visited Japan to participate in the 3rd International Micromachine Symposium. We interviewed him, and asked about recent trends of NEXUS and the situation of micro system development at Sextant.

Q1: Could we have some background information about the NEXUS?

A1: NEXUS is a Network of Excellence funded by the European Commission to promote research, development, production and application of microsystems. NEXUS was established in 1992 and started as an academic driven organization. In 1995, NEXUS was shifted from an academic initiative to an industrially driven network, and it was called NEXUS II. This year, we are in the new phase NEXUS III. NEXUS-PAN which was organization built up in parallel of NEXUS in central and eastern European countries and they organized the same and started by mainly institute in their countries. Now, we are integrated NEXUSPAN within the same organization. So we can enlarge NENUS on Pan European, from western Ireland to eastern Russia. Next year, we will start the NEXUS IV phase and foresee the future of NEXUS as a self funded organization in the 2000's.

Q2: What kind of activities will NEXUS put emphasis on in the future?

A2: As NEXUS moved for an industrial driven activity, one main goal was to pass from "technology push to the market or products pull" and in this way, User Supplier Clubs were established as the most important basic activity. The idea of these clubs is for each application area of MST to bring together MST suppliers, MST users focused on that application, and related R&D institutes. There are the following five groups, Automotive, Medical & Biomedical, Aerospace & Geophysics, Instrumentation & Process Control, and Peripherals & Multimedia. Each club has members of 15 to 30 companies and institutes, organizes three to four meetings per year and workshops. Market analysis, technology needs, products performances and standards are analyzed by each of them. The future plans of NEXUS are to improve the User Supplier clubs structures and programs, to carry on an in-depth market analysis for MST/MEMs in Europe and to establish a Strategic Guidance Group. This group is a task force for collecting information from Market Analysis, each User Supplier Club, the benchmarking missions and also from Academic Working Group. So the strategic guidance group will compile every information, which makes the synthesis and have guidance, guidelines, key targets for the future for the European Commission, and the entire NEXUS community.

Q3: Could we have some information concerning microsystem of your company?

A3: Our company, Sextant Avionique, is a subsidiary of Thomson CSF group in France. We have 6,000 employees, dealing with civil and military avionics systems for flight control, man machine interfaces, instruments and navigation. As for microsystem, our company is a world leader in high-performance sensors for the avionics systems and oil field services, including pressure, acceleration, angular rate and magnetic sensors. We developed those sensors using electromechanics techniques and micromechanics for fine mechanics during the 70's and the 80's. We moved into microsystem on MEMS, using silicon and quartz bulk micromachining techniques in the mid 80's, because the techniques could give us the capability for still being leader by faster miniaturized design, high performance and lower cost. The Sensor Unit of SEXTANT Avionique has 100 employees involved in R&D and production of microsystems. There are 2000m2 cleanrooms with a four inch wafer production lines.

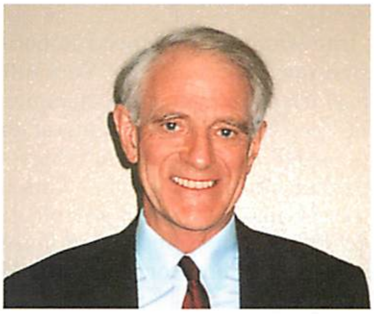
Q4: How do you feel about Japanese Micromachine R&D project?

A4: It seems to me that the Micromachine Program is a large "umbrella" project within which futuristic systems could be developed. Even though these projects appear to be exotic, they give the means of collaboration between the companies and mainly the possibility for each partner to develop individual devices in order to enhance its products on the market. It is also very impressive to me that Japanese companies are going to exploit quickly the advantage of microsystem to their product.

Q5: Could you tell us your dream about micromachine?

A5: I have two dreams. As far as my business is concerned, I would like to have the latest best performance products developed by my company using MST/MEMS, to increase the market share in the high end products for aerospace and oil field services systems. In the other hand, I would say that my personal dream is mainly in the area of medical and health. When looking at all the developments of the MST or MEMS for medical and bio-medical applications, I would say that this will be a great issue for a better way of life for everybody in the 2000's.

Interview with Prof. Dorey of Imperial College, U.K.



Professor Howard Dorey of Electric and Electronic Engineering Department, Imperial College, U.K., visited Japan to participate in the 3rd International Micromachine Symposium. We interviewed him, and asked him about standardization trends in IEC and the status of micro system development at Imperial College.

Q1: Could we have some information about the standardization of Microsystems in IEC?

A1: We have not had any meetings of the IEC working group concerning the standardization of Microsystems yet. So far we have been concerned about setting it up and making sure that we works in with Japanese standardization, German standardization and so on. So the first meeting will be held on December. We are now in early stages, so we are trying to make sure what is the most important standard. Different workers want standards for specific devices, for example medical catheters, so that they are compatible. Others want standards for dimensions, processes, packages, materials and many other subjects. We need to talk to each national representative and ask what they wish to do first. We may have to vote on priorities. This stage could well take several months before we can start on the first standard.

Q2: Could we have some information about MCIG (Microengineering Common Interest Group)?

A2: There are many bodies in UK concerning the microengineering or micromachine. MCIG is a Common Interest Group. It has about 50 membership groups. The members are colleges and companies. It has two types activities. These two types of activities are basically how to make micromachines and how to use them in a particular application. The MCIG usually holds its meetings at a placement of major manufacturer or at a major user. In both cases we want to know about their problems and how we can help solve them. As the recent interest of MCIG, the next meeting would be reported from the mission of reading Japan. We have also started to organize meetings on problems in hospitals and in mass production factories.

Q3: What kind of researches concerning microsystem technology are being carried out in your college (Imperial College)?

A3: In the electrical & electronic engineering department, there are three teams researching microsystem technology. One team are working on optical devices and optical switches, and also on mass-spectrometer. They use glass and silicon as major building materials. Another team works on displays, which makes small parts to promote big displays. The third team works on the eyes, which uses laser Doppler to monitor the flow of blood on the back of the eye. The chemical engineering department also works on chemical sensors. In the medical research group, almost of all uses micro-engineering. There are over 100 research areas at my college. They range through the design of miniature IR and UV spectrometers, mass spectrometers, optical switching systems, the measurement and control of water quality for the water companies, the optimization of aircraft engines, minimally invasive surgery on the brain, heart, stomach, intestines, kidneys and other organs. I guess that there are about 2000 researchers concerning microengineering, and the half of them are user of micro-engineering.

Q4: What kind of new technology will be need in the near future?

A4: The new technology that will be needed in the near future includes packaging that is completely compatible with the micromachines, perhaps even made of the same material. Chemical sensors and actuators in the design stages will need to be taken into mass production at lower costs than are now offered. Some interesting work is needed here. The design of surgical tools that can safely be used within the body for some period of time still presents a number of interesting challenges. Wherever I look, I find new requirements and the list is endless.

Q5: Could you tell us your dream about micromachine?

A5: My dream about the micromachine is that it will serve our everyday needs and that the uses will outnumber those of electronic devices within ten years. Devices that actually do things for us rather than electronic devices that tell you what to do would be very, very welcome. Let us think of some everyday uses. The shoe that checks how you walk and changes to protect your feet is one lovely dream. Clothing that automatically adapts its insulation and moisture resistance to the temperature and humidity is another. However, I think automatic tennis rackets and golf clubs that improve the way you appear to play should be banned!

16th IARP Joint Coordinating Forum

International Advanced Robotics Program (IARP) started upon agreement at Versailles Summit in 1982, as a place of information exchange and discussion of robot related R&D situations of industrialized countries. IARP runs many workshops including the Joint Coordinating Forum (JCF). This time, the 16th JCF was held and attracted people from 11 countries. From Japan, Mr. Komoriya, a manager at Mechanical Engineering Laboratory, and Mr. Muroi, a manager at MMC, joined us.

[Period]

10:15-17:00, September 29 (Mon.), 1997
8:40-15:00, September 30 (Tue.), 1997

[Place]

Conference Room at Canadian Space Agency, Saint-Hubert, Quebec

[Contents]

The convention started with explanations of the situations of robot development in China and Brazil, which attended as observer countries, and formal enrollment of Russia was proposed. Then each country reported their events and future action plans. Japan proposed to hold a humanoid robot workshop in October 1998, and won approval by extending the theme to human robot coexistence technology. The workshop will, by agreement, be held on October 26, 1998.

After that, trends of development of advanced robot technology in each country were reported.

Japan reported the direction of future R&D, and introduced examples of activities, including research of friendly network robotics that started Leading Research in fiscal year 1996. Also reported on were a bipedal humanoid robot recently developed by an automobile manufacturer that has drawn much attention at home, and research of micromachine technology by the Industrial Science and Technology Frontier Program.

As for research of micromachine technology, outlines of research and development of four experimental systems, functional device technology, and common basic technology that are run in the second phase of the program were explained.

Micromachine technology is recognized as one of the important areas for future robot technology both in Japan and abroad. Brazil and China, which attended the forum for the first time, showed special interest.

Then action plans for IARP were put together and Japan's proposal to hold the next JCF in Japan on October 27 and 28 was agreed. (The schedule of the next JCF meeting was timed to coincide with the human coexistent robotics workshop and the 4th International Micromachine Symposium to be held after the workshop on October 29 and 30, 1998.)

Participants

Australia:	Dr. S. Ramakrishnan	CSIRO, Manufacturing Science and Technology
Austria:	Dr. Peter Kopacek	Technische Universität Wien
Canada:	Dr. David G. Hunter	Space Station Program, Canadian Space Agency
France:	Mr. Georges Giralt	CNRS, Robotics and A. I. Group
Germany:	Dr. Tomas Martin	Federal Manufacturing Technologies and Quality Assurance Programmes, Forschungszentrum Karlsruhe GmbH
Italy:	Mr. Giuseppe Mosci	Elsag Bailey - A Finmeccanica Company
Japan:	Dr. Kiyoshi Komoriya	Department of Robotics, Mechanical Engineering Laboratory
Japan:	Mr. Nobuyoshi Muroi	International Exchange Department, Micromachine Center
USA:	Mr. Norman Caplan	Division of Bioengineering and Environmental Systems, National Science Foundation
Russia:	Dr. Valery G. Gradetsky	Institute for Problems in Mechanics, Russian Academy of Sciences
China:	Dr. Zhen-Bang Gong	Shanghai University
Brazil:	Dr. Liu Hsu	Dept. Electrical Engineering Coppe/UFRJ

Participants of IARP Joint Coordinating Forum (JCF)

Topics

Report from Sino-Japanese Joint Micromachine Workshop

Upon a proposal made in May 1996 by Prof. Zhou Zhaoying, Dean, Tsinghua University, the master of Precision Equipment and Machinery Section, a Sino-Japanese joint micromachine workshop has been in preparation. During three days from September 28 to 30, 1997, the workshop took place at Tsinghua University in Beijing.

Japan made a presentation on three points:

(1) Current situations of micromachine technology in Japan, including MEMS

(2) Activities of MMC

(3) Results of Industrial Science and Technology Frontier Program

Prior to the workshop, participants from Japan met people of State Education Commission of China, National Natural Science Foundation of China, and State Scientific and Technological Commission of China, which sponsored the workshop. It indicates that the Chinese side places much importance on this workshop. According to them, many people from all over China wished to attend, but were unable to because of limits on the number of participants. All the Chinese participants are researchers belonging to academic societies, colleges, universities, and research institutes. Nobody attended from business enterprises. The presentation focused on MEMS based on semiconductor technology. An associate professor from the Mechanical Engineering Department of National Chiao Tung University came from Taiwan. It seemed that politics did not cast a shadow over research and development.

In the presentation, the Chinese side seemed not to fully understand the necessity of microfactory, probably because of insufficient preparation of industrial and social infrastructure in the country. Then, Japanese side actively took up microfactory during the Q&A time at a round table and explained the basic concept in Japan of R&D of micromachine technology. As a result of this, it seemed they understand the direction that Japanese R&D is aiming at. Questions from the Chinese side included many about future applications, but more were about technical details. The impression was that China is still at the basic, laboratory and experiment level and that it would take time for them to start the industry. The Japanese participants suggested carrying on R&D focused on MEMS while keeping future extension in mind.

This joint workshop, thanks to the efforts by Professor Zhou, made the activities of the MMC known extensively in China, and helped recognition of the current situations and future direction of R&D in Japan. We firmly believe that all of China will have a great interest in micromachine technology and MEMS after this workshop.

Sino-Japanese Joint Micromachine Workshop

The participants are listed below.

Japan:

Prof. Naomasa Nakajima, The University of Tokyo
Prof. Hiroyuki Fujita, The University of Tokyo
Dr. Tokio Kitahara, Research Official, Mechanical Engineering Laboratory, AIST, MITI
Mr. Tatsuaki Ataka, General Manager (Division Executive), Seiko Instruments Inc.
Mr. Takashi Kurahashi, Project Manager, DENSO CORPORATION
Dr. Hiroshi Takada, Senior Assistant General Manager, SUMITOMO ELECTRIC INDUSTRIES, LTD.
Mr. Hiromu Narumiya, Manager, MITSUBISHI ELECTRIC CORPORATION
Mr. Kazuhisa Yanagisawa, General Manager, OLYMPUS OPTICAL CO., LTD.
Mr. Takeshi Yoshioka, Project Manager, MITSUBISHI HEAVY INDUSTRIES, LTD.
Mr. Takayuki Hirano, Executive Director, Micromachine Center
Mr. Toshiyoshi Okazaki, General Manager, Micromachine Center

China (part):

Prof. Ding Henggao, Chinese Academy of Engineering
Prof. Li Zhijian, Tsinghua University
Prof. Jin Guofan, Tsinghua University
Prof. Wang Liding, Chinese Academy of Science
Prof. Zhou Zhaoying, Tsinghua University
Prof. Bao Minhang, Fudan University
Prof. Cai Hegao, Harbin Institute of Technology
Prof. Tian Zhaowu, Xiamen University
Prof. Liang Chunguang, Hebei Semiconductor Research Institute
Prof. Gao Zhongyu, Tsinghua University
Prof. Jiang Zhuangde, Xian Jiaotong University
Prof. Li Chuanqi, University of Science and Technology of China
Prof. Lu Zuhong, Southeast University

Living Organisms and Micromachines (III)
Insect Nerve System, Hint for Control Systems

Isao Shimoyama
Department of Mechano-informatics, The University of Tokyo

1. Introduction

Although their brains and nerve systems are tiny, every insect has some mechanism for taking necessary behavior to survive. By studying this mechanism, we can get some idea of micro robot control systems.

It is thought that the behavior of an insect is caused by some program, that is, a fixed behavior prompted by input information from sensors to the brain, and by reflex movement. The details remain unknown, but in a recent movement of neuro-ethology they try, through integrating the macro approach of ethology and micro approach of neurophysiology, to explain the total mechanism of the nerve system which receives stimuli and takes action as a response.

2. Small Control System

Restrictions in weight and volume of a micromachine inhibits mounting of complex advanced control systems. There must be a simple small control system that implements functional requirements of a micromachine. Let me argue the possibility of a small control system for a micromachine based on the behavior program of an insect, specifically, the silkworm moth.

In a simple environment, fixed and reflex behavior of an insect is observed at high reproducibilities. For instance, a male silkworm moth proceeds toward the source of a pheromone, that is, a female. If a pulse stimulus of the pheromone is given to the right antenna of the male, it walks in a zigzag pattern yawing its body, and then starts walking clockwise in a circle. The directions of the first turn of the zigzag walking and the circle walking are determined by which of the right or left antennae received the stimuli. The stimulated side is memorized until the next time either antenna is stimulated. In a natural environment, where pheromone flows in a complex distribution pattern, the moth is thought to act on this program each time a pheromone molecule hits either antenna, and takes a series of actions responding to the sensor inputs.

According to Kanzaki's physiological experiment, the input of pheromone from the antennae to the brain is confirmed in the mutually inhibiting nerves connecting the right and left brains. Pheromone information is passed down to the motor system in the thorax and generates pheromone oriented behavior. The mutually inhibiting connection works as a flip-flop, retaining the side where the pheromone hits an antenna until either antenna is stimulated next time. Therefore, the action of a male silkworm moth moving toward its mate is expressed by a model consisting of a flip-flop memory in the brain, nerve system, and a basic behavior program that is restarted by a pheromonal stimulus. We presumed that orientation toward the source of the pheromone emerges from the complex pheromone distribution by reruns of this mechanism activated each time the stimulus is given.

Walking and flapping of a silkworm moth are not directly controlled by the brain. Even if information from the brain is removed, a silkworm moth still walks and flaps. Those motions are directed by the motor neurons in the thorax. The brain gives a command to the motor system such as the direction of movement.

3. Orienting Mobile Robot

We mounted pheromone sensors made of silkworm moth antennae onto the mobile robot shown in Figure 2, to check the explained activation pro-

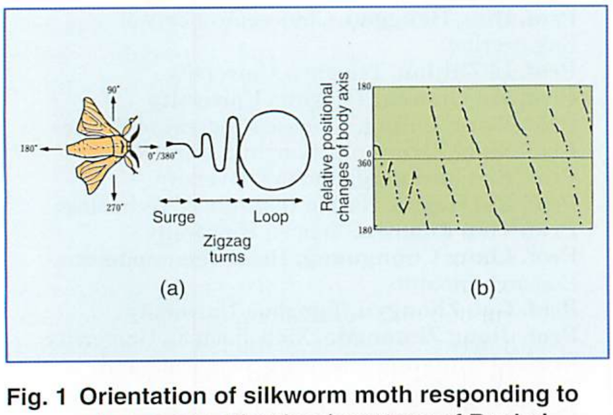


Fig. 1 Orientation of silkworm moth responding to pheromone stimulus (courtesy of Ryohei Kanzaki of University of Tsukuba)

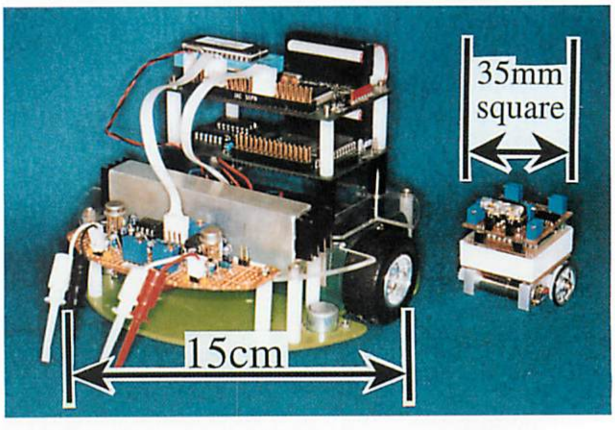


Fig. 2 Mobile robot with pheromone sensors

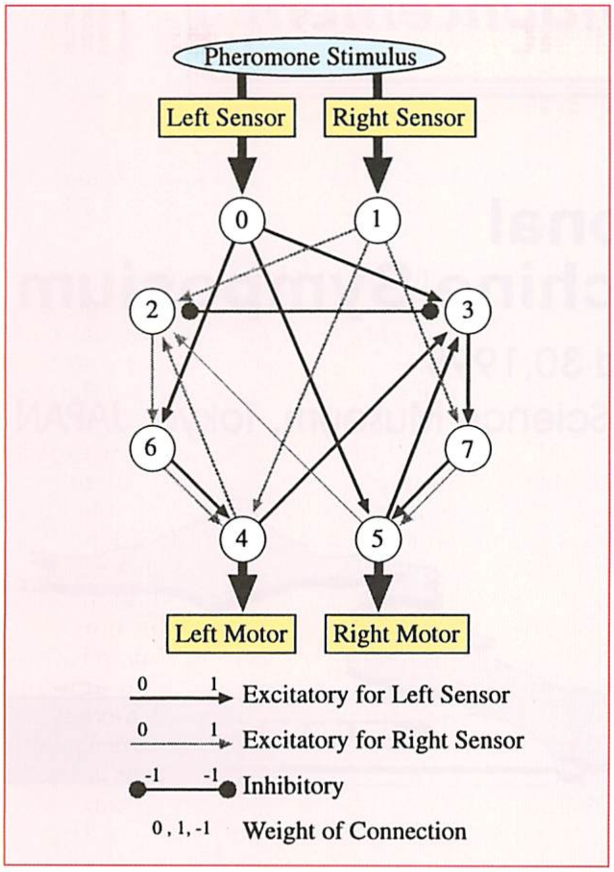


Fig. 3 Neural net for control of the mobile robot

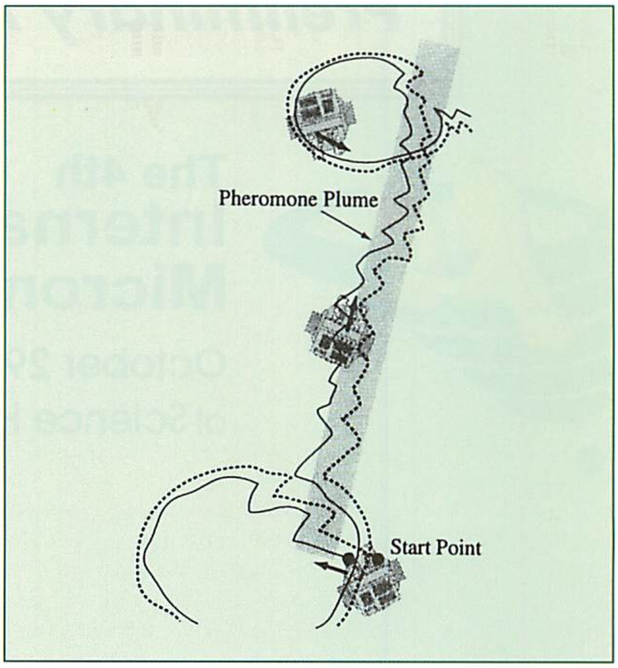


Fig. 4 Robot moving in presence of pheromone

gram. These pheromone sensors are not affected by air stimuli but respond only to the female silkworm moth pheromone. Since the responding action of a male silkworm moth to the single pheromone stimulus is zigzag walk followed by walking in a circle, we programmed the neural net shown in Figure 3 to make the robot simulate the moth behavior. Signals from the right and left antennae are input to sensor neurons 0 and 1, respectively, then the outputs from motor neurons 4 and 5 control the robot motor. The inhibiting connection between neurons 2 and 3 forms the RS flip-flop where which of the right and left antennae has been stimulated. Neurons 2, 6, and 4 form one sequence circuit, and neurons 3, 7, and 5 form another. Each circuit corresponds to circle walking of a single period. Figure 4 shows the actual motions of the robot in the presence of the pheromone. As shown in the figure, just like a real silkworm moth, the robot moved in a zigzag pattern when the pheromone intermittently hit the antennas, then it started walking in a circle in search of the flow of pheromone when it diverted from the pheromone flow and the pheromone stimulus to the antennas stopped.

If one takes a closer look at the orientation of a male silkworm moth toward a female, one can observe that the male solely depends on the pheromone information when the female is away, but when the two get closer, the male uses other sensors than the antennae to accomplish mating. When different sensors are receiving different sorts of stimuli, how these data are used is unknown, however. Another notable point is that neural net is usually operated with the use of clock signals to each neuron for synchronization. Whereas as far as we know real silkworm moths do not use such synchronizing signals. This means that the signals propagating through nerves of living organisms probably contain time information. Thus, much is left to be learned from the nerve system of living things.

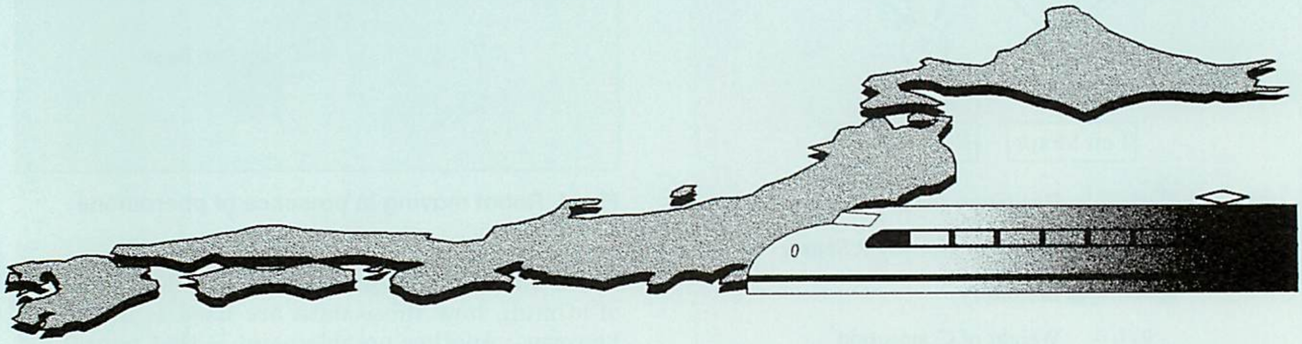
4. Conclusions

We saw possibilities for micromachines that mimic a living nerve system focused on the example of the silkworm moth. I am sure there will be many living organisms other than the silkworm moth that give us ideas for making micromachines. As I mentioned in the previous installment of this article series, not only common properties of all living organisms but also particularities of species can be helpful for making micromachines. We have been studying the function and structure of insects to make micromachines. In the meanwhile, we discovered that micromachines can be an instrument for the study of insect brains. In the studies of the brain so far, the relationship between the brain and behavior has been studied analytically. However, no matter how scrupulous the analysis of the brain and nerves may have been, the whole mechanism of behavior activation upon stimuli is not yet explained. By integrating analytical results in the form of a micromachine and making comparison with actual behavior of the insect, this mechanism can be studied. And the use of micro electrodes fabricated by micromachining is expected to acquire new data that has been unavailable so far.

Preliminary Announcement

The 4th
International Micromachine Symposium

October 29 and 30, 1998
at Science Hall, Science Museum, Tokyo, JAPAN



Exhibition
MICROMACHINE '98

October 28 ▸▸ October 30, 1998
at Science Museum, Tokyo, JAPAN

Exhibition
MICROMACHINE '98

The Detail will be announced later.

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