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No. 27

Increasing Expectations for Micromachine Technology

Dr. Tsuneo Ishimaru
Chairman, Micromachine Center

Research and development into micromachine technology is currently being undertaken in earnest by research organizations around the world as a key technology for the 21st century. However, worldwide attention is being focused on the approach towards micromachine technology development by Japan, which has taken on this wide technical field.

The research and development project into micromachine technology promoted as a ten-year project based on the Industrial Science and Technology Frontier Program of Agency of Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI) enters its ninth year this year. It is therefore at the stage of summing up the research results. I believe that in the remaining two years it will be important both to finalize the results achieved in the research in a visible form, and also to give concrete indications of practical applications of the technology developed. Practical applications have already been designated for some of the research achievements, and studies into practical uses have already commenced. However, much of the technology has not currently reached a level suitable for practical applications. There will be increasing expectations of efforts by the participating businesses and organizations in the future in order to put the results of this project into practice in the 21st century.

Amid the long-lasting sluggish economy worldwide, the government has injected large amounts of capital into a wide range of business sectors as emergency economic measures to revive the economy as quickly as possible. As well as trying to revitalize the business world, determined measures have been set up to stimulate consumption among the general public, including tax cuts and the issuing of regional promotion vouchers. Meanwhile, however, environmental problems typified by global warming and dioxin pollution have become increasingly acute, with growing criticism of the mass consumer culture to date. Amid this situation, micromachine technology not only offers potentially environmentally-friendly features such as energy saving, resource saving and space saving, but also possesses the ability to enrich people's lives by creating new industries and reviving the economy. It can certainly be described as a technology eagerly awaited in the world today. Since last year, micromachine technology has frequently been covered in the mass media, and a large number of people from industry visited the micromachine exhibition last year hoping to find the seeds or clues for business expansion. With the largest attendance yet, it was apparent that micromachine technology is being viewed as a technology necessary by a large number of people. I therefore believe that it is necessary now to show the practical directions of the results achieved to date in the research and development, and also to put efforts into activities promoting these to the world in an easy-to-understand form.

And while actual results such as these are much awaited, awareness has also increased towards the direction of research and development of micromachine technology in Japan from a long-term viewpoint following the completion of the current micromachine project. At this center also, we believe that we must select research and development tasks for the next steps and examine the direction of future micromachine developments.

We hope that you gain and understanding of the work of this center, and we look forward to your support.

Intelligent Cooperative Systems Laboratory

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

1. Introduction

Micromachines are useful in the fields of information, science, and biology which offer promise. That is because minuteness is essential in these fields. In the field of information, reduced size, weight, and thickness of data equipment creates immediate performance and cost advantages. In the field of science, there are still unexplored areas in the world of microscopic particles at the atomic level and nanometer/micrometer levels that could not be handled until now. Likewise, in the field of biology, the cells that comprise our bodies are microscopic structures at a micrometer level, therefore technology for handling these at micrometer levels will play an important role.

Based on these, our laboratory (biological intelligence systems field) at the Research Center for Advanced Science and Technology carries out research into microscopic work in three areas: (1) The information equipment area to contribute to practical technology for future high-density electronic devices, (2) the science area aiming to reveal the construction of microscopic structures with dimensions in the order of the wavelength of light and their interactions with light, (3) the biology area aiming to make possible the manipulation of minute organs inside the cells. This report describes the latest achievements and future potential for each of these areas.

2. Latest achievements

2.1 Research into high-precision automatic assembly techniques (achieving automatic "pick & place")

[Goal and details]

The research is to assemble microscopic components of micrometer (mm) order for information devices under an electron microscope at nanometer order precision (10nm? or 100nm order) with high reliability. With this in mind, a robot manipulator is developed which has a visual- and movement-concentrated configuration. This robot is able to focus the viewing axis together with all the rotational degrees of freedom of the manipulator on a single point as shown in Fig. 1. Research has also been conducted into pick & place techniques to manipulate polymer micro-spheres automatically using needle tools.

[Achievements and future work]

Following progress in analysis of the mechanics that define the operations, it is noted that interfacial coupling between objects advances with the initial electrostatic force due to charging under an electron microscope, and that the adhesion force increases with time. Furthermore a rolling-resistance moment acts on the microscopic object due to the elastic deformation at the contact surface. The rolling-resistance moment for an external moment corresponds to a frictional force for an external translational force. The adhesion force and the rolling-resistance moment were used to propose a "pick" technique for separating the interface between the object and the substrate on which it is placed, and a "place" technique for separating the interface between the object and the needle tip attached to it. It is confirmed experimentally that "pick and place" operation is performed with high reliability by two methods. The offset pushing method presses down a point slightly offset from the center of the sphere towards the base as shown in Fig. 2(a). The shearing-trajectory method moves the tool in a direction slightly downwards from the tangential direction in relation to the contact interface between the needle tool and the sphere as shown in Fig. 2(b). A future work is to apply these methods to various materials and configurations. Those results show that provided the mechanics of the microscopic world are correctly understood, the behavior of microscopic objects previously thought to be uncertain can controlled simply by correctly determining the trajectory of the manipulator.

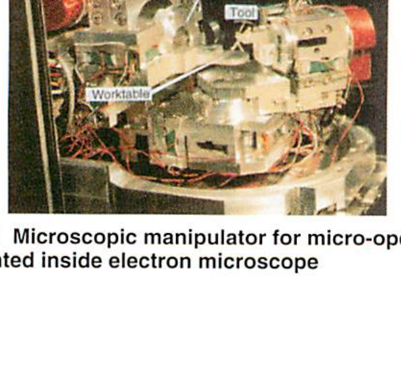


Fig. 1 Microscopic manipulator for micro-operation mounted inside electron microscope

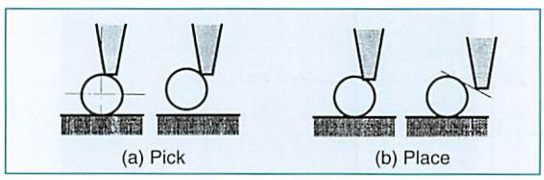


Fig. 2 Trajectories for high-reliability "Pick & Place"

2.2 Research into photonic structures using build-up construction techniques

[Goal and details]

Fig. 3 shows various types of waves, wavelengths and structures for making use of them. In the radio wave region, structures such as Yagi antennae are used with complex shapes and sizes of the same order as the radio waves. In the light wave region, however, it can be seen that only structures such as lenses or prisms are used that are unreasonably large when considering the light-wavelength. This is because until now the technology to allow free manipulation of microscopic objects of the light-wavelength order (nanometer to micrometer level) was not available. Our laboratory has established techniques for the three-dimensional arrangement (build-up construction method) of individual micrometer-order spheres, and has also researched the interaction of light with complex-shaped structures (named photonic structures) built in this method with dimensions of the light-wavelength order.

[Achievements and future work]

The following key techniques are established as essential techniques in the work arranging micro-spheres. These include substrate coating techniques for positioning the micro-spheres, wet dropping techniques for dispersing micro-spheres onto the substrate without cohesion, grading techniques for selecting spheres of the same diameter, manipulation techniques based on elastic contact, refocusing techniques for rapidly finding previous work positions, and evaluating techniques for the shape of the created structures. Examples of photonic structures created using these techniques are shown in Fig. 4. The behavior of light with these light-wavelength order microscopic three-dimensional structures is currently becoming clear. In practice, by assessing the two-dimensional photonic crystals in Fig. 4 optically, it is proved that with an increasing number of crystals, the photonic band enlarges and converges into the results of theoretical calculations. Likewise, it is also noted that because of the dependency on the angle of photonic crystal's

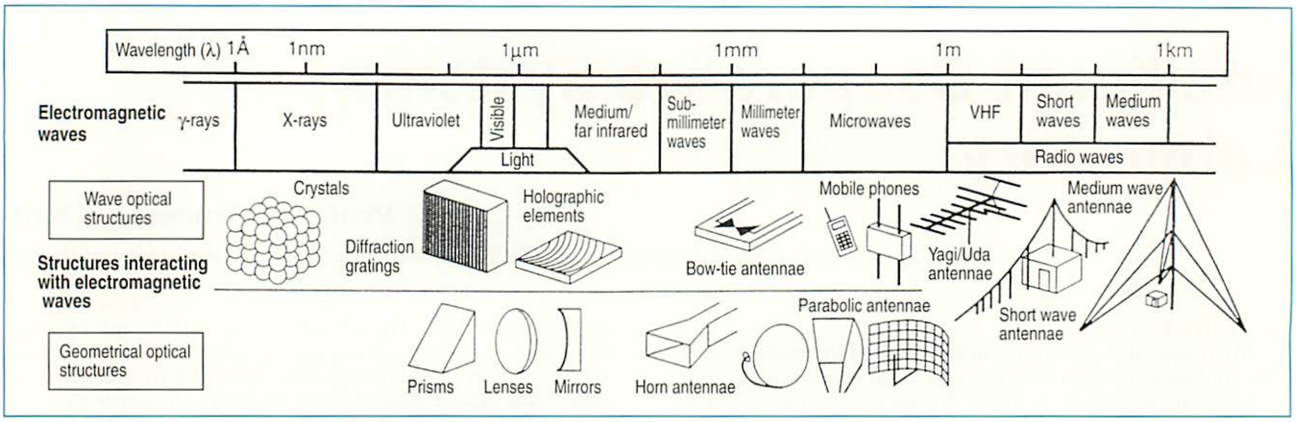
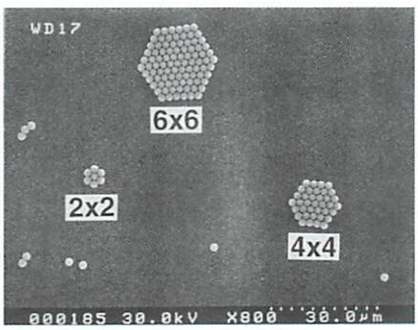


Fig. 3 Different types of waves, wavelengths, and structures for using them

transmission spectrum, the unusual dispersion phenomena occurs due to multiple dispersion of the structure arising from the light and the micro-sphere arrangement. Establishing methods for constructing totally controlled dispersion body arrangements is the breakthrough in photonic structure research, and the methods are currently expected to enable achieve filters, interconnections, spectral discrimination, and high-sensitivity detection devices with features hitherto impossible.



Monolayer fcc Photonic Crystals

Fig. 4 Actual photonic structures achieved by manipulation of individual microscopic particles

2.3 Research into manipulating minute organs inside cells

[Goal and details]

In the field of biology, research has been conducted into the separation and collection of granular substances collecting Mato cells. Mato cells are special cells that exist on the blood vessel walls within the brain, and are cells that are known to store up granular substances that emit fluorescent light related to aging.

In order to analyze what these granular substances are, attempts have been made to collect only the Mato cells by separating them from other cells using a robot manipulator.

[Achievements and future work]

A micro-operation system has been constructed enabling minute organs to be handled inside the cells under high-magnification optical microscopes. With high-magnification microscopes, the distance between the objective lens and the specimen is reduced to the order of millimeters, therefore attempting to manipulate the specimen in the gap becomes extremely difficult due to the reduced manipulator stiffness. In order to overcome this problem, the system is developed so that the preparation on which cells are mounted under the microscope acts as the manipulator arm (preparation manipulator). Control is achieved 1) using a method that shows the operation with the work status obtained from a visual sensor, and 2) features data expression and a database expanding MPEG4 in order to save operation data from the system together with the image data. A "status on demand" function is also made possible which 3) uses stored operation data as an aid to subsequent work. Using the developed operation system, it is proved that it is possible to separate and collect Mato cells. It is also proved that it is possible to record the cutaway and separation of Mato cell surroundings using expanded-MPEG4-data-expression methods and a database. Likewise, it is shown to be possible to correct the operation data and re-use it (Redo function), and to give a summary presentation of the operation by displaying multiple images showing changes during the operation (operation summarization function). It is anticipated that techniques such as these for manipulating cell interiors microscopically will become widely used in the medical and bio-engineering fields in addition to biological fields.

3. Conclusion

At the Sato Laboratory in Research Center for Advanced Science and Technology, we are pushing ahead with research into the basics of a) increased intelligence and b) reduced size to bring the research closer to biology as the direction in which to advance machine systems. As research towards increased intelligence, we are also promoting research into a robotic room in which the room itself is a robot that protects personnel without notice and supports them when required. Meanwhile, as described in this report, research into reduced size is continuing in the form of research into micro-operations in the fields of data devices, science and biology, in which minuteness is.

The fields of micro-operations are not limited to those described above, and cover a wide range as well as new fields in which research has only just begun (underlined), as shown in the verb lists in Fig. 5. Refining these verb groups in the micro or nano worlds does not just involve revealing the mechanisms, but is also expected to form key technologies opening up new industries. Even if the required effort becomes greater, we believe that it is vital to make progress one step at a time. If this report has introduced just part of these research activities we would be so much pleased.

Fig. 5 The scope of micro-operations

Overview of MMC's Activities in Fiscal 1999

In F.Y. 1999 the Micromachine Center (MMC) will implement the following five programs with the aim of establishing the basic technologies for micromachines and increasing utilization of micromachines.

① Investigations and research on micromachines,
② Collection and provision of micromachine information,
③ Exchange and cooperation with worldwide organizations involved with micromachines,
④ Promotion of standardization of micromachines,
⑤ Dissemination and education about micromachines.

I. Investigations and Research on Micromachines

The industrial Science and Technology Frontier Program of MITI's Agency of Industrial Science and Technology (AIST) has entered the forth year of its second term. To achieve the goal of the basic plan for the R&D (Phase II), the R&D system will be further improved and research delegated to MMC will be actively promoted. Also MMC will exchange technical information with researchers in various countries and provide results of investigations and research for those concerned in and outside of Japan.

1. The AIST's Industrial Science and Technology Frontier Program "Micromachine Technology" (This project has been delegated to MMC by the New Energy and Industrial Technology Development Organization (NEDO).)

Based on the R&D results on fundamental device technology in the first phase, the ultimate purpose of this project is to establish technologies applicable to the realization of micromachine systems. These systems are mechanical systems composed of small functional elements that locomote within very narrow spaces in complicated equipment used at power plants and other facilities and inside of the human body. They can also perform intricate work autonomously, and produce small industrial products as a microfactory.

(1) Development of advanced maintenance technologies for power plants

① R&D of systematization technology (Experimental wireless micromachine for inspection on inner surface of tubes)

R&D of systematization technology will be conducted through production of an experimental system for a wireless micromachine. Inside a metal tube with a curved section, this micromachine will be able to move forward, backward, horizontally and vertically, stop optionally, and recognize its surroundings as well as detect defects of tubes.

R&D topics promoted are realization of an experimental wireless micromachine for inspection on inner surface of tubes through developing a locomotive device and a microwave energy-supply/communication device as the main technology, and systematization of a microvisual device and an optical energy transmission device.

② R&D of systematization technology (Experimental chain-type micromachine for inspection on outer surface of tubes)

Systematization technology will be developed through production of an experimental micromachine system composed of a group of single machines capable of combining or separating according to the form of the object to be inspected.

R&D will promote the following topics: creation of an experimental chain-type micromachine for inspection on outer surface of tubes through developing a driving device to propel the machine, and systematization of reduction and traveling devices and a microconnector.

③ R&D on systematization technology (Experimental catheter-type micromachine for repair in narrow complex areas)

R&D on systematization technology will be conducted by producing an experimental micromachine system capable of entering the equipment of various structures and performing measurements or repairs of minute internal flaws.

R&D topics promoted are: creation of an experimental catheter-type micromachine for repair in narrow complex areas through developing multi-degrees of freedom flexible pipe structure; and systematization of a position detection device and a monitoring device.

④ R&D of functional device technologies

R&D will be conducted to promote micronization, high performance, and multi-functionalization of functional devices that form the components necessary to realize future micromachine systems and highly advanced micromachine technology.

R&D will focus on creating the following: an artificial muscle, microjoint, low-friction suspension device, rechargeable micro-battery, optically driven free joint device, etc.

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⑤ R&D of common basic technologies

R&D will be conducted on common basic technologies such as technologies for control, measurement, design, and evaluation necessary for realizing micromachine systems.

R&D will center on achieving pattern forming technology for a group of distributed micromachines, hierarchical group control technology, measuring technology for micromachines, etc.

⑥ Comprehensive investigation and research

Comprehensive investigation and research on micromachine technology will be promoted including investigation and research to conduct the basic design of maintenance micromachines necessary for maintaining future power plants, and leading investigations and research on micromachine systems expected to be used for maintenance.

(2) Development of microfactory technology

① R&D of systematization technology (Experimental processing and assembly system)

R&D will be conducted on systematization technology by producing an experimental system for processing and assembling capable of manufacturing models of small parts by integrating processing, assembly, conveyance, and inspection machines in a limited narrow space.

R&D topics promoted include: micro processing technology, micro assembling technology, micro fluid technology, micro optical driving technology, micro electric driving technology, micro conveyance technology, and micro inspection technology.

② Comprehensive investigation and research

Comprehensive investigation and research on micromachine technology will be promoted. This will include the influence of microfactories caused by such problems as electromagnetic interference generated when various devices are integrated or concentrated in a small space, and advanced research on micromachine systems to be used in production.

In addition, we will conduct the analysis of the economic efficiency of microfactories, in conjunction with AIST's Mechanical Engineering Laboratory, and research on enhancing the performance of micro-electron guns for beam processing jointly with AIST's Electrotechnical Laboratory.

(3) Research and development of micromachine technology

① Research on micromachine systems

In the medical field, R&D on miniaturization and multifunctionality of micro-laser catheters and micro-tactile sensor catheters will be conducted. These catheters are the major functional components of a micro-catheter for diagnosis and treatment of cerebral blood vessels, an intraluminal diagnostic, and therapeutic system.

② Comprehensive investigation and research

Comprehensive investigation and research on micromachine technology will be carried out on the future applications of micromachine system to the medical field. In conjunction with AIST's Mechanical Engineering Laboratory, MMC will also conduct research on micromachine basic design and manufacturing technologies.

2. R&D of Micromachine Materials

Jointly with the Mechanical Engineering Laboratory of AIST, MMC will conduct ① research on the operating environments for micro functional elements, ② research on micromachine materials, and ③ feasibility studies on micromachine materials.

3. Research on the Applicability of Emerging Technology in Other Fields to Micromachine Technology (activities to help promote the machine industry)

Pursue joint efforts among government, academia and industry to search out emerging technology in other necessary fields in order to promote the diversification and practical use of micromachine technology, and to verify its applicability and fusion. This will strengthen the technology and contribute to its diffusion and encouragement. We will search out emerging technology in the bioscience, chemical, physical science and medical fields.

4. Study of Overseas Applications of Micromachine Technology (delegated activities to promote the machine industry)

Micromachine technology R&D is yielding a steady stream of results, and is already showing useful social effects through partial incorporation in products. This practical technology is attracting attention in various industrial circles.

As with information communications-related fields, particular note is made of practical applications of the technology as they emerge in specific form. Analysis of the route to practical use has the objective of accelerating introduction of new technology into various industrial fields. We will research applications of micromachine technology both domestically and overseas, and analyze the technical content.

5. Study of Futuristic Element Technology of Micromachine Systems

With regard to the various systems proposed heretofore, we will adjust their element technologies organizationally, research their trends (including the overseas segment), and study the future direction and technical issues of micromachine systems.

6. Investigation on R&D Trends of Micromachine Technology in Japan and Abroad

MMC will analyze the current state of research and development on rapidly progressing micromachine technology in Japan and abroad, and develop a body of information on the basic technologies for developing micromachine technologies.

II. Collection and Provision of Micromachine Information

Information and documents on micromachines in universities, industry, and public organizations in Japan and overseas will be collected, combined with survey results and documents produced by MMC, and made freely available in the MMC library.

III. Exchange and Cooperation with Worldwide Organizations Involved with Micromachines

To promote affiliation, exchange, and cooperation with related organizations in and outside Japan, MMC will implement the following. ① Provide research grants to research activities at universities for R&D on micromachine technology as part of its promotion of joint research with government, industry and academia. ② Invite authorities from Europe and the U.S., and dispatch authorities and researchers from Japan, to promote overseas exchanges. ③ Dispatch research missions overseas. ④ Participate in the 5th Micromachine Summit and undertake bilateral technical exchange (activities to help promote the machine industry, partly). ⑤ Hold the 5th International Micromachine Symposium (activities to help promote the machine industry, partly). ⑥ Hold joint seminars and workshops overseas.

IV. Standardization of Micromachines

Based on progress in standardization as planned in F.Y. 1998, MMC will implement the following. ① Promote the Micromachine International Standardization Forum established in F.Y. 1998. ② Cause micromachine glossary to reflect the results of the Forum, while at the same time expanding content from the standpoint of international standardization. ③ With regard to measurement evaluation methods, study collation of past research results into a comprehensive technical report, pursue research into specific standardization topics deemed necessary, and move to standardize their technical issues.

V. Dissemination of and Education about Micromachines

In order to achieve wider utilization of micromachines, MMC will implement the following. ① Issue public information publications. ② Hold the 6th Micromachine Drawing Contest, seminars on micromachines, briefing session on research results, and preparation of videos. ③ Hold the 10th Micromachine Exhibition. ④ Serve as the Federation of Micromachine Technology Secretariat.

The Research Subjects for the 6th Micromachine Technology Research Grant

The research subjects for the 6th Micromachine Technology Research Grants (for F.Y. 1998) were selected at the Board of Directors meeting held in March 1999. As a result of a rigorous screening and examination process, seven new research subjects and five ongoing research subjects (2nd year) were selected from a large number of applications, as shown in the appended table. A total of ¥18.5 million in financial assistance grants will be presented. This research grant program was started in F.Y. 1993 as an independent activity of the Micromachine Center, and provides financial assistance to researchers engaged in basic research on various aspects of micromachine technologies. It is aimed at providing support for further progress of micromachine technologies, and at promoting exchange and cooperation between industry and academia.

On March 24, 1999, a ceremony to award the research grants was held at the Tokai University Alumni Hall in the Kasumigaseki Building. Dr. Tsuneo Ishimaru, Chairman of the Micromachine Center, gave the sponsor's greeting. Mr. Masahiro Fujita, Director, Industrial Machinery Division of MITI, gave his guest speech, and Prof. Yoji Umetani, Chairman of the Industry-Academia Joint Research Committee of the Micromachine Center, reported on the results of the screening. Following this, financial assistance awards were presented to the twelve researchers who were selected. Prof. Shigefumi Nishio of The University of Tokyo spoke on behalf of the grant recipients. Later, each of the seven researchers on the new research subjects that were selected gave overview of his research, followed by an informal discussion.

Applications for the F.Y. 1999 research grant program will be solicited and accepted from July to October of this year.

The new research subjects that were selected for the 6th Research Grant are summarized in the following pages.

Subjects for the 6th Micromachine Technology Research Grant

New Research Projects Granted for Fiscal 1998

Leader & Co-Worker	Affiliations	Subjects	Period
Prof. Masao Washizu, Dr. Eng.	Department of Mechanical Engineering, Kyoto University	Molecular surgery of DNA based on microsystems	2 Years
Prof. Kazunori Kataoka, Dr. Eng. Dr. Atsushi Harada	Department of Materials Science, Graduate School of Engineering, The University of Tokyo Research Associate, Department of Materials Science, Graduate School of Engineering, The University of Tokyo	Structural design of "chemical nano-machine" based on the self-organization of polymers and its application to targeting therapy	2 Years
Dr. Tooru Ooya	Research Assistant Prof., School of Materials Science, Japan Advanced Institute of Science and Technology	Study on biomedical micromachine using biodegradable supramolecular assembly	2 Years
Dr. Hiroshi Toshiyoshi Prof. Hiroyuki Fujita, Dr. Eng.	Lecturer, 3rd Division, Institute of Industrial Science, The University of Tokyo 3rd Division, Institute of Industrial Science, The University of Tokyo	Micromachine system for micro-optical smart pixel application	2 Years
Prof. Shigefumi Nishio, Dr. Eng. Dr. Kiyoshi Takano	2nd Division, Institute of Industrial Science, The University of Tokyo Research Associate, 2nd Division, Institute of Industrial Science, The University of Tokyo	Experimental study on fluid flow and heat transfer inside micro-channel utilizing micro-machining technology	2 Years
Dr. Osamu Nakabeppu	Research Associate, Faculty of Engineering, Tokyo Institute of Technology	Development of dynamic-valve type micro-pump driven by bubble oscillation	1 Year
Assoc. Prof. T. H. Barnes	Physics Department, University of Auckland	Low-noise feedback interferometry for micromachine servo actuators	2 Years

Carried-Over Projects Granted for Fiscal 1997

Leader & Co-Worker	Affiliations	Subjects	Period
Assoc. Prof. Toshihiro Itoh, Dr.	Research Center for Advanced Science and Technology, The University of Tokyo	Plasma etching using scanning probe microscope	2nd Year
Prof. Shuichi Shoji, Ph.D. Dr. Osamu Tabata	School of Science and Engineering, Waseda University Associate Professor, Faculty of Science and Engineering, Ritsumeikan University	Fundamental study on microchip for DNA analysis	2nd Year
Prof. Katsutoshi Kuribayashi, Dr. Eng. Dr. Seiji Shimizu	Faculty of Engineering, Yamaguchi University Research Associate, Faculty of Engineering, Yamaguchi University	Development of pre-stretching method of SMA thin film actuator on Si wafer	2nd Year
Prof. Tadashi Matsunaga, Dr. Eng.	Faculty of Technology, Tokyo University of Agriculture and Technology	Development of a nano-probe for detection of a cell surface protein	2nd Year
Dr. Kenji Suzuki	Lecturer, Graduate School, Faculty of Engineering, The University of Tokyo	Measurement and control of friction in micromachines	2nd Year

Mr. Fujita, Director of Industrial Machinery Division, MITI, gives his greeting.

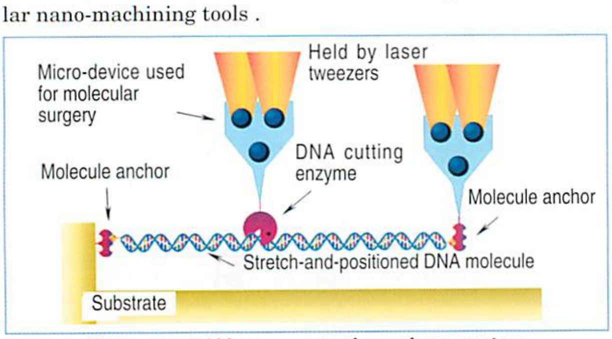
Researchers who received research grants for F.Y. 1998

Outline of the New Subjects for the 6th Micromachine Technology Research Grant

Molecular surgery of DNA based on microsystems

Masao Washizu
Kyoto University

Micromachine technology is used here for "molecular surgery of DNA", where DNA is stretched into a linear shape and fixed onto a predetermined position on a solid surface, and then cut or chemically modified using AFM (atomic force microscopy) stylus or laser-manipulated micro particles on which DNA enzymes are immobilized. The technology enables operations of a specific position on the DNA molecule, such as assays or deletion/insertion of genes, which was not possible in conventional biochemistry. In addition, through direct observation of the mutual interaction between DNA and enzymes, it will open the way toward basic researches on the activities of enzymes as molecular machines, and utilization of enzymes as molecular nano-machining tools .

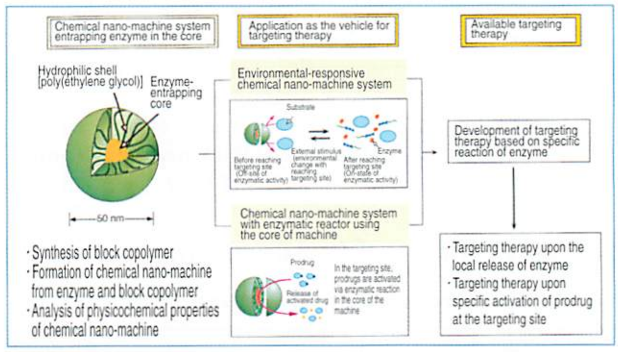


Molecular DNA surgery using micro-system

Structural design of "chemical nano-machine" based on the self-organization of polymers and its application to targeting therapy

Kazunori Kataoka and **Atsushi Harada**
The University of Tokyo

In this study, we will prepare macromolecular assembly possessing a nano-scale core-shell architecture entrapping enzyme in the core. This macromolecular assembly can be useful as environmental-responsive chemical nano-machine system controlling the formation and dissociation of the assembly synchronized with the external stimulus, or as chemical nano-machine system with enzymatic reactor using the core of the machine. Particularly, it was expected that this micromachine technology is available in the field of enzyme targeting of drug delivery system.

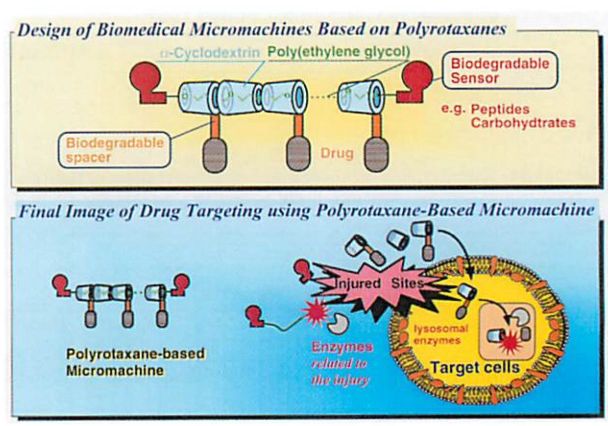


Localized treatment with chemical nano-machine systems containing enzymes

Study on biomedical micromachine using biodegradable supramolecular assembly

Tooru Ooya
Japan Advanced Institute of Science and Technology

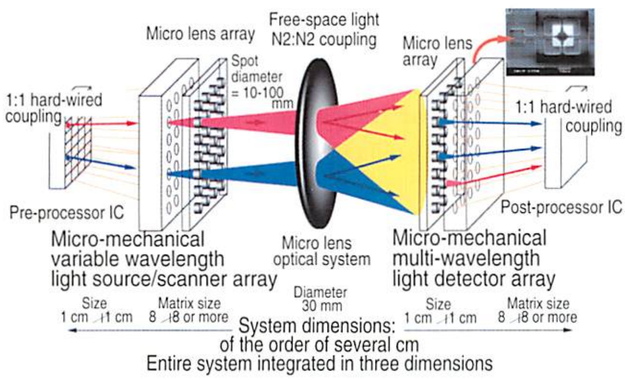
The aim of this study is to develop a medical micromachine using biodegradable polyrotaxanes, in which many cyclic molecules are threaded onto a polymeric main chain, capped with biodegradable sensors. The biodegradable sensors at the ends will recognize injured sites and be degraded by injury-related enzymes, releasing a drug-cyclic molecule conjugate via supermolecular dissociation. The conjugate then delivers the drug into target cells. By tailoring the biodegradable sensors to respond injury-related stimuli, we will establish new micromachines that can recognize specific disease and treat the disease.



Micromachine system for micro-optical smart pixel application

Hiroshi Toshiyoshi and **Hiroyuki Fujita**
The University of Tokyo

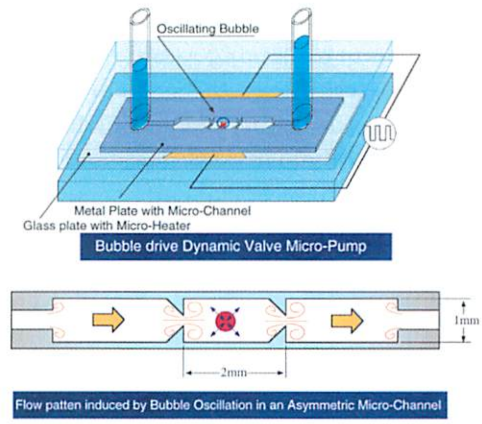
A great deal of research is currently underway in the area of smart pixels-the use of light to connect IC chips in the very small free space between the chips. In this study, we will investigate the use of micromachine technology in two-dimensional integration of micro-mechanical optical elements such as miniature scanners and wavelength filters, and in the development of an advanced optical element matrix capable of modulation of light beams with respect to time, space, and wavelength dispersion. Our research will provide valuable information in the area of optical communication switching matrix systems and optical computing.



Development of dynamic-valve type micro-pump driven by bubble oscillation

Osamu Nakabeppu
Tokyo Institute of Technology

The dynamic valve pump (DVP) is a device that oscillates fluid in asymmetric channels and utilizes differences in resistance in the flow direction to move the fluid in a given direction. The structural simplicity and absence of mechanical wear make the DVP ideal for miniaturization applications. In this study, we will: investigate fluid motion inside a miniature DVP and clarify the underlying principles of motion; consider the potential of the DVP in a micromachine system; and attempt to further simplify the pump structure by developing a miniaturized DVP based on oscillation of vapor bubbles in the flow channels generated by periodic heating.



Experimental study on fluid flow and heat transfer inside micro-channel utilizing micro-machining technology

Shigefumi Nishio and **Kiyoshi Takano**
The University of Tokyo

As electronic devices such as ICs become faster and more complex, they generate more heat, requiring the development of techniques for the efficient removal of heat generated in small spaces. At the same time, small flow channels may bring about thermal and flow-related phenomena that cannot be explained in terms of conventional theory. In this study, we will measure flow and heat transfer characteristics and investigate the relationship between the dimensions of the flow channel and unusual thermal and flow-related phenomena. In this way, we hope to provide some valuable insights for use in estimating the amount of heat removal in micro-devices.

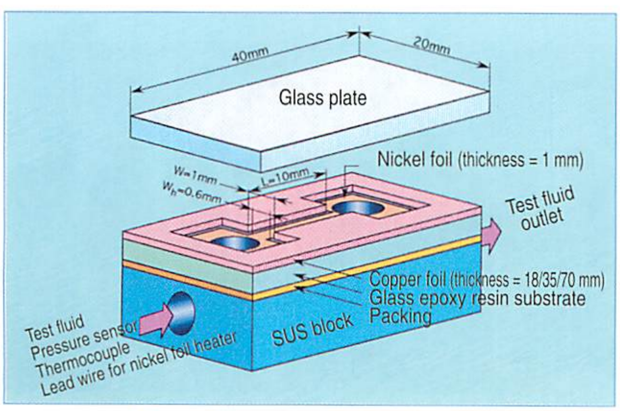


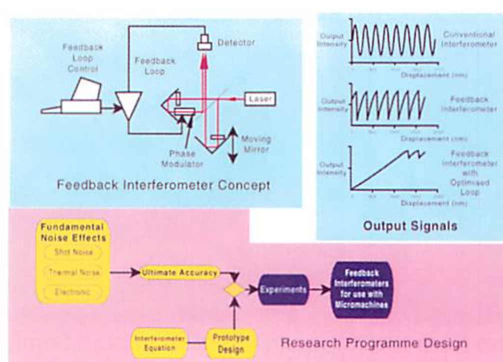
Fig. 1 Structure of micro-channel

Low-noise feedback interferometry for micromachine servo actuators

Thomas H. Barnes
University of Auckland

High-accuracy displacement measurement is a fundamentally important technology for the development of micromachines. Optical interferometry potentially has sufficient accuracy, but suffers from ambiguities caused by the cosinusoidal fringe profile. However, application of feedback round an optical interferometer produces a saw-tooth fringe profile and reduces both ambiguity and non-linearity. Optmisation of feedback parameters can provide an output nearly proportional to displacement over several wavelengths.

We will determine the accuracy limits of feedback interferometers, set by fundamental physical phenomena such as shot- and thermal-noise. We will also develop techniques for optimising feedback loop parameters to maximise the linear range of operation. This will be done by theoretical investigation, and experiments on a prototype feedback interferometer system.



Kanazawa Micromachine Seminar

The Kanazawa Micromachine Seminar was held on the afternoon of Friday February 5, 1999, at the Ishikawa Prefecture Local Industry Promotion Center under the joint auspices of the Micromachine Center (MMC), Ishikawa Prefecture, and the Ishikawa Prefecture Industrial Development Fund Association's Ishikawa Trial Center. The event was also supported by the Ishikawa Prefecture Small Business Information Center, Ishikawa Prefecture Ironworking Machinery Association, and Hokuriku Joint Research Association.

In addition to explaining recent developments in micromachine technology, the seminar presented an overview of Micromachine Technology Research and Development, an Industrial Science and Technology Frontier Program project currently being carried out under MMC's leadership. Four concrete results from the project were also presented.

In addition, during breaks, Mr. Yoshiki Kuroda and Mr. Hiromu Narumiya gave demonstrations of "1-mm Diameter SMA Micro-Actuator" (made by OLYMPUS OPTICAL CO., LTD.) and "Micro Generator" (made by MITSUBISHI ELECTRIC CORP.), both of which were exhibited on site. The exhibits and presentations provided a good opportunity for the attendants to learn about micromachine technology.

The first half of the seminar was presided over by Mr. Seiichi Niimura, Deputy Director of the Ishikawa Prefecture Industrial Development Fund Association's Ishikawa Trial Center. The second half was presided over by Mr. Yoshihiro Matsuda, Manager of the same Center's Administration Department.

The program opened with a welcome by Mr. Koichiro Iwata, Director of the Ishikawa Prefecture Industrial Testing Center, after which a series of presentations ensued. MMC Executive Director Takayuki Hirano spoke about "MMC's Activities"; Mr. Noriaki Ozawa, Deputy Director of the Industrial Machinery Division of the Ministry of International Trade and Industry, spoke about "Japan's Policies Regarding International Trade and Industry"; Dr. Tomomasa Sato, Professor at The University of Tokyo spoke about "Present State and Future Direction of Micromachine Technology"; and Dr. Yuichi Ishikawa, General Manager of MMC's Research Department, gave "An Outline of the Second Phase of the Micromachines Project".

The seminar also included the following presentations on results of the Industrial Science Technology Frontier Project.

"Development of Tactile Sensors"
Mr. Yoshiki Kuroda (OLYMPUS OPTICAL CO., LTD.)

"Multi-Functional Monitoring Device Research and Development"
Mr. Hiroshi Goto (OMRON Corp.)

"Micromachine Approaches to Medicine"
Mr. Tsuyoshi Kudo (TERUMO CORP.)

"Micro-Component Assembly Processes by Magnetic Applications"
Mr. Hiromu Narumiya (MITSUBISHI ELECTRIC CORP.)

On the day of the seminar, Ishikawa Prefecture was blanketed with its first major snowfall in over a decade. Nonetheless, the seminar drew 80 attendants, including 44 persons from 33 companies involved in the precision machinery, ironworking, laser processing, and medical care industries of Ishikawa and Toyama Prefectures. The remaining 36 attendants were from universities, research facilities, and government agencies. The seminar proved to be a meaningful gathering punctuated by lively question-and-answer sessions following the presentations.

A scene from the Kanazawa Micromachine Seminar


Attendants observing a demonstration of potable micromachine technology exhibits

Fifth Micromachine Drawing Contest Award Ceremony Held

The Micromachine Drawing Contest sponsored by the Micromachine Center (MMC) for elementary and junior high school students was held this year for the fifth time. Pupils from 14 elementary and 7 junior high schools in the cities of Gifu (Gifu Prefecture), Omiya (Saitama Prefecture), Takasago and Kobe (both in Hyogo Prefecture) entered this year's contest. The contest was conducted with the cooperation of MMC's supporting members Mitsubishi Heavy Industries, Ltd., and Mitsubishi Materials Corp., as well as the Tsukuba/Keihanna Gifu Prefecture Information Center.

This year's contest garnered an all-time record of 1,464 entries, 976 in the elementary school category and 498 in the junior high school category. The participating schools were as follows.

The participating schools

Elementary Schools:

Sone Municipal Elementary School* (Hyogo Prefecture)
Takasago Municipal Elementary School (Hyogo Prefecture)
Iho-minami Municipal Elementary School (Hyogo Prefecture)
Iho Municipal Elementary School (Hyogo Prefecture)
Takasago Korean Elementary School (Hyogo Prefecture)
Arai Municipal Elementary School (Hyogo Prefecture)
Kitahama Municipal Elementary School (Hyogo Prefecture)
Hamayama Municipal Elementary School (Hyogo Prefecture)
Higashi-maiko Municipal Elementary School (Hyogo Prefecture)
Kotabayama Municipal Elementary School (Hyogo Prefecture)
Hontamon Municipal Elementary School (Hyogo Prefecture)
Kano Municipal Elementary School (Gifu Prefecture)
Sakuragi Municipal Elementary School (Gifu Prefecture)
Omiya-minami Municipal Elementary School (Saitama Prefecture)

Junior High Schools:

Takasago Municipal Junior High School* (Hyogo Prefecture)
Syoyo Municipal Junior High School (Hyogo Prefecture)
Arai Municipal Junior High School (Hyogo Prefecture)
Kashima Municipal Junior High School (Hyogo Prefecture)
Utashikiyama Municipal Junior High School (Hyogo Prefecture)
Kano Municipal Junior High School (Gifu Prefecture)
Sakuragi Municipal Junior High School (Saitama Prefecture)

* School prize awarded.

A jury listed below selected 12 artworks from the elementary school category and 13 from the junior high school category. The selected artworks are shown on the following pages.

Jury

Dr. Hirofumi Miura (Chief), Professor, Kogakuin University
Dr. Yoshinori Nakazawa, Director-General, Mechanical Engineering Laboratory, Agency of Industrial Science and Technology, MITI
Dr. Keiko Nakamura, Deputy Director General, Biohistory Research Hall
Dr. Ryoze Yamashita, Associate Professor, Tokyo National University of Fine Arts and Music
Mr. Takayuki Hirano, Executive Director, Micromachine Center

The award ceremony was held on March 26 at the Tokai University Alumni Hall on the 33rd floor of the Kasumigaseki Building in Tokyo. It was attended by some 40 persons, including the best entry prize and the first prize winning pupils, school members, guests, and the juries.

At the award ceremony, Mr. Makoto Okazaki, Director for Machining and Aerospace R&D, AIST, MITI made a speech to the children. "It will soon be 10 years since we set out to develop micromachines based on a vision of key technologies that would support Japan's economy and industries in the 21st century. However, practical application of such technology is not easy. I hope this contest proves to be a springboard for at least one or two of you to someday enter the fields of science, technology, or research and development."

Professor Miura, the Chief of the jury, reported on the judging process and commented on the work submitted. He said, "There is a Chinese proverb, 'A frog in a well knows not the vast ocean, but it knows the depth of the sky.' This is analogous to adults whose creative ideas are limited by an overabundance of knowledge. In contrast to such adults, children whose minds are still largely unfettered and brimming with curiosity have wonderful ideas. Please enter another ingenious drawing again next year," he warmly said.

Following the introduction of the selected drawings, testimonials and prizes were awarded to Koji Naito (6th grader of Sone Municipal Elementary School in Hyogo Prefecture) in the elementary school category and Yasuyo Komatsu (3rd grader of Takasago Municipal Junior High School in Hyogo Prefecture) in the junior high school category. In addition, the elementary and junior high schools that submitted the most submissions received school awards.

After receiving the award, Miss Komatsu expressed her hopes for the future: "I got the idea for my drawing when I thought, Wouldn't it be great to have such a handy device. I hope that in the future micromachines useful to people will play an active role in the world."

After the ceremony, four portable micromachine technology exhibits were displayed at the hall. The children and teachers alike crowded around the exhibits, their eyes gleaming in wonder at the first actual micromachines they had ever seen.

Commemorative photograph of award winners

Winners of the Fifth Micro

Elementary School Category:

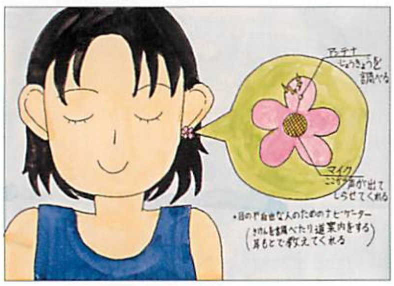
Best Entry Prize
Micro ultrasonic lure

Koji Naito
Sone Municipal Elementary School (6th grade)

First Prize
Micromachine making micromachine

Hiroshi Haruki
Omiya-minami Municipal Elementary School (5th grade)

Second Prize
Navigator for vision handicaps



Maki Nakahara
Kitahama Municipal Elementary School (4th grade)

Second Prize
Underwater exploration machine

Yumi Ogasawara
Sone Municipal Elementary School (5th grade)

Third Prize
Mr. Washer Boy

Yukari Kondo
Takasago Municipal Elementary School (5th grade)

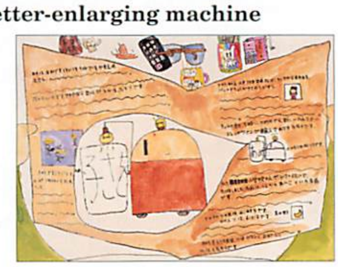
Third Prize
Micro-soccer tournament

Iruru Kitano
Sone Municipal Elementary School (5th grade)

Third Prize
Air cleaners for toxic gases

Yuta Yamazaki
Sone Municipal Elementary School (6th grade)

Honorable Mention
Letter-enlarging machine



Saki Emoto
Hamayama Municipal Elementary School (5th grade)

Honorable Mention
Insect killer

Ryo Morishita
Hamayama Municipal Elementary School (5th grade)

Honorable Mention
Mr. Cleaning Man

Rino Oosone
Sakuragi Municipal Elementary School (4th grade)

Good Idea Mention
Mr. Mini-Carpenter

Yuri Ri
Takasago Korean Elementary School (6th grade)

Good Idea Mention
Micro plane

Syogo Hayashida
Hamayama Municipal Elementary School (5th grade)

machine Drawing Contest

Junior High School Category:

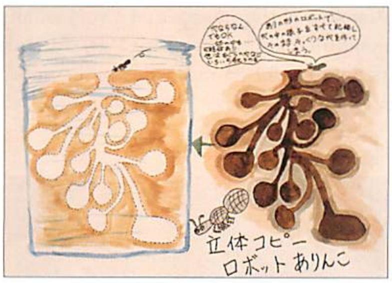
Best Entry Prize
Cleaner robot "Clean"

Yasuyo Komatsu
Takasago Municipal Junior High School (3rd grade)

First Prize
Bee-type robot

Yumi Murata
Takasago Municipal Junior High School (2nd grade)

Second Prize
3-dimentional robot "Ant"



Risa Kamatani
Takasago Municipal Junior High School (2nd grade)

Second Prize
Good-to-have-it

Tomoko Matsuda
Takasago Municipal Junior High School (2nd grade)

Third Prize
Flood predictor/detector

Masayo Hanamitsu
Arai Municipal Junior High School (2nd grade)

Third Prize
Take-it-all

Hikari Maki
Takasago Municipal Junior High School (3rd grade)

Third Prize
Petit-machine

Sayoko Tsubouchi
Takasago Municipal Junior High School (2nd grade)

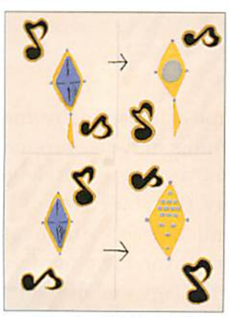
Honorable Mention
Manicure machine

Saho Amano
Takasago Municipal Junior High School (2nd grade)

Honorable Mention
PC cleaner

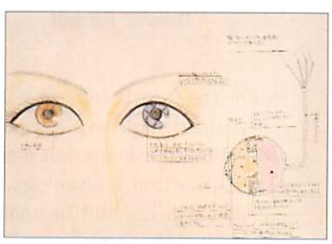
Sayaka Arashi
Takasago Municipal Junior High School (3rd grade)

Honorable Mention
Sound pierce & sound controller



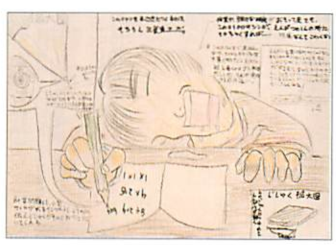
Kyoko Tateishi
Takasago Municipal Junior High School (1st grade)

Good Idea Mention
Seeing artificial eye



Seiko Murata
Takasago Municipal Junior High School (3rd grade)

Good Idea Mention
Easy-automatic-pencil-machine



Yusuke Sotani
Arai Municipal Junior High School (1st grade)

Good Idea Mention
Honey producer machine

Chihiro Mori
Kano Municipal Junior High School (1st grade)

Matsushita Research Institute Tokyo, Inc.

Sadahiko Yamashita
President

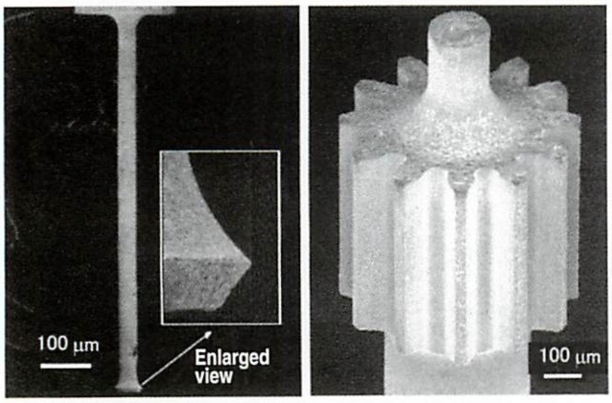
1. The Challenge of Micromachine Technology

In line with the increasing popularity of mobile information-processing devices such as compact, high-performance optical discs and video cameras, micromachine technology is increasingly important as a means of producing components at the sub-millimeter level. However, the technology needed in associated areas, such as new processing and measurement methods and motion mechanism analysis techniques at the micro level, is yet to be developed. Through our research into very small mechanisms of propagation, Matsushita Research Institute Tokyo is working on these areas as part of the Industrial Science and Technology Frontier Project of the Ministry of International Trade and Industry.

2. Development of Micromachine Technology

In Phase II of the Industrial Science and Technology Frontier Project, we are developing micro reducer for chain-type micromachine for inspection on outer surfaces of tubes consisting of multiple devices linked together. The micro reducer is based on a mechanical reduction gear used to efficiently reduce the high-speed rotation of an electromagnetic motor and propel the inspection system. The research includes an element technology to realize very small mechanisms of propagation.

As for micromachining technology, we realize three-dimensional micromachining using micro-electro-discharge machining technology (Fig. 1). In light of the problem of electrode wear and the limitations of processing speed, we conducted research into the mass-production of electrodes by LIGA process and the viability of batch style discharge machining. Using a ϕ 100-μm bronze processing electrode array, we were able to create 12 holes simultaneously (Fig. 2). The ability to mass-produce electrodes with precision and a degree of flexibility with respect to shape suggests that micro-electro-discharge machining has considerable potential as a rapid and reliably consistent solution.



(1) Vibroscan stylus (2) Gear

Fig. 1 Components produced via micro-electro-discharge machining

A vital aspect of upgrading micromachining is process feedback, that is, measuring the machined shape and the shape of the processing electrodes 'on-machine'. We are developing an on-machine measuring technique that is a combination of image processing and the vibroscan method, in which minute but deep holes and narrow sections are measured within processing fluid. Vibroscan method is a precision technique for measuring the shape of small objects which uses contact detection to determine the positional relationship of the sample and a very small, oscillating, discharge-machined stylus (see Fig. 1(1)). At this stage, vibroscan appears suitable for on-machine applications.

3. Future Challenges

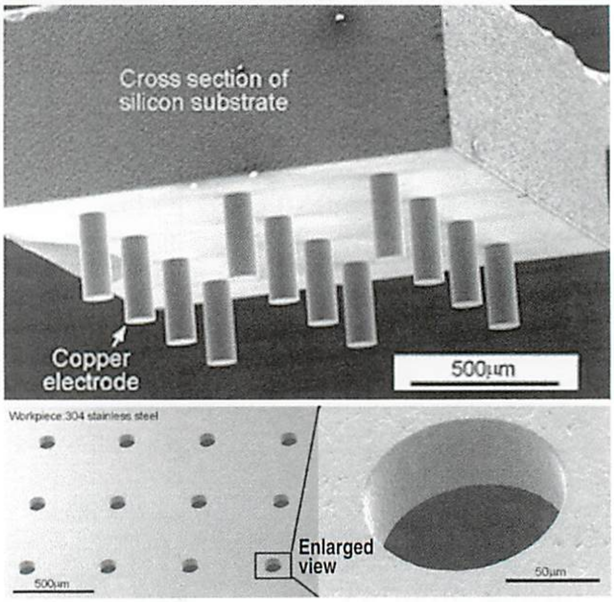


Fig. 2 Micro-electro-discharge machining with multiple electrodes
Above: Electrodes
Below: Result

For the time being, we will continue establishing technology for the design, evaluation, machining, and measurement of very small propagation mechanisms, as well as developing systematization technology, both are the objectives of the Industrial Science and Technology Frontier Project. At the same time, we will be studying combinations involving other forms of micromachine-related element technology and developing practical applications thereof.

MITSUBISHI HEAVY INDUSTRIES, LTD.

Ayao Tsuge
General Manager, Takasago
Research & Development Center

1. The Challenge of Micromachine Technology

Mitsubishi Heavy Industries began robotics research and development nearly 20 years ago with the development of automated fuel exchange and testing systems for nuclear plants. Over the ensuring period, we have developed a wide variety of plant maintenance robots and other robot systems. More recently, we have been working on the development and application of added-value robot systems designed to not only reduce the manual component of nuclear power plant operation but also to relieve human workers from the more dirty, dangerous, and difficult tasks. Inspection and testing at power stations frequently involves confined spaces that are effectively inaccessible to robots of conventional size. Micromachine technology offers a potential solution to this problem.

2. Development of Micromachine Technology

Inspection and testing in confined spaces as required at power plants requires a micromachine capable of negotiating its way over various obstacles within a cramped space. Ideally, the micromachine should be able to change shape in accordance with the shape of the obstacle. The basic premise of a robot that can alter its shape underlies research and development being conducted by Mitsubishi Heavy Industries into the holonic mechanism and control system as part of the Industrial Science and Technology Frontier Project.

Due to size limitations, the micromachine would be restricted to a single-function unit with one degree of freedom and a limited range of operations. The holonic mechanism, formed by linking together several of the single-function units, is capable of complex operations such as shape transformation and movement. Unlike conventional robots such as industrial arms, typically with a large articulated base joint and small tip, the thickness would be constant along the length of the robot body. In dynamic terms, a smaller body overall makes for a more efficient design, so the holonic mechanism would make an excellent micromachine. We are yet to see a robot supporting as many joints as the holonic mechanism. Our research at present is concentrating on structural design and device structure issues with a view to developing control systems capable of utilizing all available joints for maximum efficiency and achieving further size reduction.

Miniaturization of components such as actuators, communications and control CPUs, and sensors is only at the research stage, and we are unlikely to see development of a prototype micro-size robot for some time yet. We chose instead to develop a mechanically and electrically integrated ball joint of diameter 40 mm using the smallest ultrasonic motor currently available, and joined several of these together to form the holonic mechanism shown in Fig. 1. We then performed a simulation using the actual specifications of the holonic mechanism (including size, weight, and joint torque) and used the results to investigate control algorithms. Fig. 2 shows how use of the sawtooth waveform in the snake-like traveling wave locomotion enables the holonic mechanism to negotiate flat surfaces and steps alike with ease. With the snake-like locomotion, the load during movement is much less than for walking or the movement of a worm, making it an ideal form of locomotion for the micromachine. Meanwhile, we are also using behavior control procedures written in terms of simple behavior patterns to develop object avoidance control programs for obstacles as shown in Fig. 3.

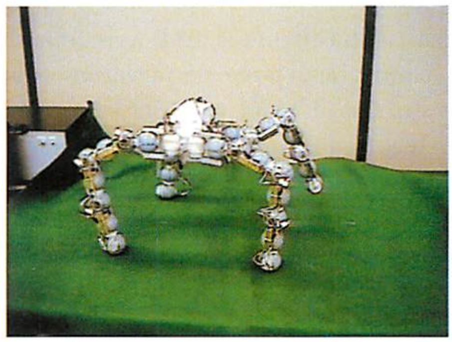


Fig. 1 Holonic mechanism

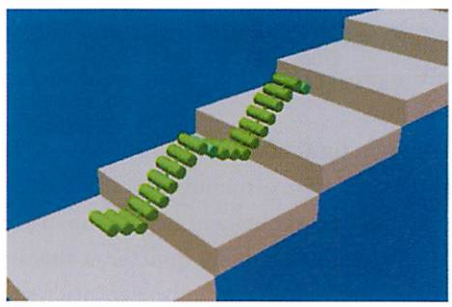


Fig. 2 Steps locomotion using waving

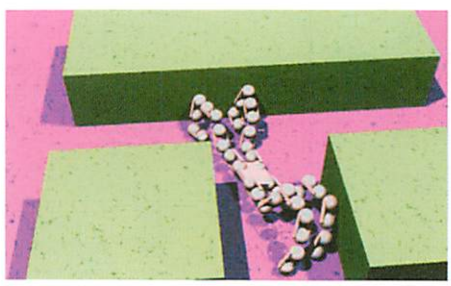


Fig. 3 Object avoidance using behavior control

3. Future Challenges

It is anticipated that micromachine technology will grow to become a fundamental area of technology used in plant maintenance and a wide variety of other fields. Mitsubishi Heavy Industries is committed to develop technology that meets the needs of the marketplace and in so doing making a valuable contribution to society.

MEMS '99 Held in Orlando MMC's Mission to U.S. Participated

1. MEMS '99

The MEMS '99 conference (IEEE) was held from January 17 to 21 at the Buena Vista Palace Hotel in Orlando, Florida. MMC's seven-person Mission to U.S. also participated in the conference.

This year's MEMS was the 12th such international conference. It was attended by 529 registered participants from 20 countries, making the second best-attended MEMS ever (last year's MEMS '98 in Heidelberg was attended by some 670 persons). An overwhelming majority of the attendees (324) were from the U.S., the host country, but a large contingent from Japan (76 persons) was also on hand. Other heavily represented countries included Germany with 18 attendees, Switzerland with 17 and Sweden with 14. As in the past, the conference was conducted in plenary sessions open to all. Although presentations were limited to 20 minutes apiece, they were marked by lively exchanges of questions and answers. In addition, this year the conference organizers made some minor changes to facilitate technical discussion among fellow researchers during the conference. For instance, the pre-prints included photographs of the presenters and poster sessions were held on the first day.

There were a total of 113 presentations, 43 of which were oral presentations (including 3 invited lectures). The other 70 were poster presentations. Japan accounted for 30 presentations, about one-quarter of the total. The other main countries in terms of presentations were the U.S. with 48, Switzerland with 9, and Korea and Germany with 6 apiece. There were six presentations concerning MITI's Industrial Science and Technology Frontier Program.

The mission together with Dr. M. Allen at Georgia Institute of Technology (Dr. Allen was also one of the coordinating members of MEMS '99)

In terms of subject matter, the presentations were broadly categorized as follows: 35 presentations on applied devices/systems, including ones related to data storage, optics, and hydraulics; 15 presentations on 3-dimensional processing technologies, including packaging and integration technologies; 10 presentations on actuators; 23 on sensors; 10 on materials and processing methods; and 17 on other topics. Like last year, there were many presentations on the results of R&D projects aimed at practical applications of micromachine technologies such as sensors and applied devices/systems. These presentations did not include anything particularly novel in terms of the underlying principles involved, but they all involved improvements or creative solutions for meeting the specifications required for practical application. In terms of new trends, there was an increase in presentations on devices that used materials other than silicon. For instance, parylene (a plastic obtained from para-xylene polymerization) was used as a polymer material in a number of devices, silicon carbide was used as a material able to withstand high-temperature environments, and germanium is being studied as a material for actualizing manufacturing processes at low temperatures when integrating devices with CMOS circuits.

MEMS 2000 is scheduled to be held from January 23 through 27 in Miyazaki, Japan. The deadline for submission of papers is September 13, 1999.

After attending MEMS '99, the MMC's mission to U.S. visited Georgia Institute of Technology and the University of California at Berkeley, where they engaged in technical discussions and investigated micromachine-related technologies. Below are summaries of the research being conducted at each university.

2. Georgia Institute of Technology

At Georgia Institute of Technology in Atlanta, the mission visited the laboratory of noted MEMS researcher Dr. Mark G. Allen, an associate professor at the Institute. We previously published an interview with Professor Allen in Issue No. 19 (published May 1997). In his lab, Professor Allen has researched a broad range of representative MEMS integrating various devices on silicon chips, including a variety of microsensors, and even hydraulic and medical-related devices. More concretely, Professor Allen has conducted research in the following MEMS-related fields.

(1) Magnetic devices (micro relay arrays, high-frequency passive components)
(2) Flow-control devices (microjet cooling devices, flow control actuators for miniature flight vehicles)
(3) Biomedical devices (micro needle arrays)
(4) Packaging (MEMS device packages using bonding technologies, etc.)
(5) High-performance sensors (pressure sensors for high-temperature applications, high-sensitivity acceleration sensors (0.1 G class), pressure sensor arrays for flow control, radio communication)
(6) Micro-combustion (turbine systems (joint research with MIT), small engines for aerospace applications, etc.)

In terms of research facilities, Professor Allen's lab is equipped with a 650 square-meter clean room and a set of semiconductor processing equipment for six-inch wafers, as well as equipment for wafer bonding and silicon carbide. It is also equipped with most everything needed to make MEMS devices, including metal-plating and parylene manufacturing equipment.

3. UC Berkeley

Located adjacent to Silicon Valley, the University of California at Berkeley has long been making major contributions to the development of semiconductor devices. It likewise has a long history in MEMS research. The university generates prolific research results, primarily through the Berkeley Sensor and Actuator Center (BSAC), where R&D is done on microsensors, micro-actuators, micro mechanical structures, and micro-systems using surface micromachining technologies that employ polysilicon. During the recent visit, the mission visited the lab of Associate Professor Kristfer Pister, who is conducting unique research in the world of MEMS. Namely, he has been conducting research aimed at developing three-dimensional MEMS. More specifically, he has been conducting basic research to realize silicon micro-robots using MEMS technology. Although the project is still at the stage of doing functional verification by means of macro-models and making the requisite robot parts by means of silicon surface micromachining, the ultimate objective is to realize micro-robot systems endowed with mobility and sensing and communication functions. In concrete terms, Professor Pister has been researching the following.

Dr. K. Pister explains a prototype of silicon micro-robot legs at UC Berkeley

(1) Smart dust (various components (e.g. sensors, radio communication devices, control circuits, optical elements, batteries) integrated within a package several cubic millimeters in volume; On the order of several thousands to several millions, smart dust is used for dispersed environmental monitoring, etc.)
(2) Silicon micro-robots (self-sustaining micro-robots about 1 square centimeter in size that integrate various components (e.g. sensors, infrared communication elements, control circuits, solar cells) and insect-leg-like mechanisms made of polysilicon and actuated by an electrostatic actuator)
(3) 3-D MEMS CAD tools for designing the above systems

UC Berkeley's research facilities include a class-100 clean room equipped with a set of semiconductor manufacturing equipment for 4-inch wafers (some of which can also process 6-inch wafers). Like Georgia Institute of Technology, U.C. Berkeley has nearly all the equipment needed to produce MEMS devices.

Members of the MMC's Mission to U.S. (in alphabetical order, except for MMC personnel)

Michitsugu Arima, OLYMPUS OPTICAL CO., LTD.
Masaharu Edo, Fuji Electric Corporate R&D, Ltd.
Kenzo Ebihara, FANUC LTD
Suguru Kaneko, DENSO CORP.
Yoichi Mochida, MURATA MFG. CO., LTD.
Kazuhiro Tsuruta, Micromachine Center
Nobuyoshi Muroi, Micromachine Center

Technical Terms in Micromachine Technology (v1.0) — Part 1

In this issue and next three issues, we will publish a glossary of key terms excerpted from MMC Technical Report: Technical Terms in Micromachine Technology (MMC TR-S001(01)-1998), which was published by MMC last year. For more detailed explanations, please refer to the Technical Report.

Micromachine [マイクロマシン]

[DEFINITION] Miniaturized devices of w hich components are several millimeters or smaller in size, or a microsystem that consists of an integration of such devices.

[DESCRIPTION] The term 'micromachine' has a broad sense from a functional device such as sensor that utilizes the micromachine technology to a completed system. A molecular machine that is called as a nanomachine is also included. Such industrial applications are expected as inspection and repair systems for piping or confined spaces, and micro-factories, which consume less energy. In the medical field, micromachines are expected to replace ordinary surgery by less invasive treatment from the inside of the body. Research and development for the realization of micromachine is divided into two approaches: micro electro mechanical systems (MEMS) using semiconductor manufacturing processes, and miniaturization of the existing machine technologies. **[References]** (1)(2)(3)(4)(6)

Micromachine technology [マイクロマシン技術]

[DEFINITION] A generic term for technologies relating to micromachines.

[DESCRIPTION] Micromachine-related technologies are extremely diversified. In the fundamental technology field, micromachine technologies include: design, material, processing, functional element, system control, energy supply, bonding and assembly, electrical circuit, and evaluation as well as micro-science and engineering such as thermodynamics and tribology in a microscale. Micromachine technologies have two aspects: technologies required to realize micromachines, and technologies required to apply such technical seeds to other industrial fields. **[References]** (1)(2)(3)(4)(5)(6)(7)

MST [MST]

[DEFINITION] An acronym for micro-system technologies, and a generic term for technologies relating to micro-systems.

[DESCRIPTION] The term MST is mostly used in Europe. This term mainly means technologies to realize micro electrical, optical and machinery systems and even their components by using silicon micromachining though it is occasionally used in some other meanings. **[References]** (43)

MEMS [MEMS]

[DEFINITION] An acronym standing for "micro electro mechanical systems" and a generic term for technology relating to micro-sized electromechanical systems.

[DESCRIPTION] The term MEMS is mostly used in the United States. In general this term means technologies to realize micro structures, sensors, and actuators by using silicon process technology though it is occasionally used in some other meanings. **[References]** (2)

Biomimetics [バイオミメティクス]

[DEFINITION] Creating functions that imitate the motions or the mechanisms of organisms.

[DESCRIPTION] In devising microscopic mechanisms suitable for the micromachines, the mechanisms and structures of organisms that have survived severe natural selection may serve as good examples to imitate. One example is the microscopic three-dimensional structures that were modeled after the exoskeletons and elastic coupling systems of insects. In exoskeletons, hard epidermis is coupled with an elastic body, and all movable parts use the deformation of the elastic body to move. The use of elastic deformation would be advantageous in the microscopic world to avoid the friction. Also, the exoskeleton structure equates to a closed link mechanism in kinematics and has the characteristic that some actuator movement can be transmitted to multiple links. **[References]** (6)(13)

Integrated optics [光集積回路]

[DEFINITION] An optical circuit with integrated optic components such as light emitter, photodetector, modifier, and optical waveguide.

[DESCRIPTION] Optical circuits are created by IC fabrication process, especially the multilayer thin film deposition technique including insulation layer, or silicon on insulator (SOI). The existing optics system converts optical signal to electrical signal, and converts again to the optical signal after electrical signal processing. However, the integrated optics device performs the signal processing directly in the optical integrated circuit, thereby making drastic size and weight reduction, power saving, and increasing processing speed. **[References]** (2)(7)

Micro-fluid engineering [マイクロ流体工学]

[DEFINITION] Fluid engineering for the microscopic world of micromachines.

[DESCRIPTION] Micro-fluid dynamics is characterized by smaller scales of length and velocity than in the ordinary world. In the microscopic world, based on the scale effect, the forces needed to move fluids are thought to be mainly surface force rather than body forces, that is, viscous force rather than inertial forces. The ratio of inertial force-to-viscous force is evaluated by the Reynolds number. If the Reynolds number is equal, other flows with different dimension are considered to be similar. Generally, the Reynolds number in the microscopic world tends to much smaller than that in the macroscopic world. Therefore, the use of ordinary propulsion equipment such as propellers, screws, and turbines requires special consideration in the microscopic world, because the law of similarity cannot be applied. **[References]** (1)(2)(3)(4)(5)(6)

Micro-heat transfer engineering [マイクロ伝熱工学]
[DEFINITION] Heat transfer engineering for the microscopic world of micromachines.
[DESCRIPTION] Heat transfer mechanisms in micromechanical systems are basically the same as such mechanisms for macrosystems except that the typical dimensions of the system are smaller, and therefore conventional empirical or theoretical equations cannot be directly applied. When applying conventional empirical equations relating to heat transfer, care must be taken of the value of the dimensionless parameters concerning heat transfer. The heat transfer in micromechanical systems is roughly divided into two aspects; the heat transfer within the micromechanical element, and the heat transfer surrounding or occurring in the flow of that fluid. In the former case, the heat transmits as a result of thermal conduction, while in the latter case, the heat transfer accompanying the fluid's movement must be considered as well as thermal conduction. In both cases, it is necessary to release the heat generated within the element outside the system. Otherwise, the temperature of the system rises, impairing the accuracy of the system. Accordingly, the design of the heat releasing system is extremely important, particularly if the amount of heat generated in the element is large. **[References]** (4)

Micro-science and engineering [マイクロ理工学]
[DEFINITION] Science and engineering for the microscopic world of micromachines.
[DESCRIPTION] When mechanical systems are miniaturized, various physical parameters change. Two cases prevail: 1) these changes can be predicted by extrapolating the changes of the macro-world, and 2) the peculiarity of the microscopic world becomes apparent and extrapolation is not possible. In the latter case, it is necessary to establish new theoretical and empirical equations for the explanation of phenomena in the microscopic world. Moreover, new methods of analyses and syntheses to deal with engineering problems must be developed. Material science, fluid dynamics, thermodynamics, tribology, control engineering, and kinematics can be systematized as micro-sciences and engineering supporting micromechatronics. **[References]** (1)(2)

Micro-tribology [マイクロトライボロジー]
[DEFINITION] Tribology for the microscopic world of micromachines.
[DESCRIPTION] Tribology deals with friction and wear in the macroscopic world. On the other hand, when the dimensions of components such as those in micromachines become extremely small, surface force and viscous force become dominant instead of gravity and inertial force. According to Coulomb's law of friction, frictional force is proportional to the normal load. In the micromachine environment, because of the reaction between surface forces, a large frictional force occurs that would be inconceivable in an ordinary scale environment. And very small quantity of abrasion that would not become a problem in an ordinary scale environment can fatally damage a micromachine. Micro-tribology research seeks to reduce frictional forces or to discover conditions that are free of friction, even on an atomic level. In this research, phenomena that occur with friction surfaces or solid surfaces at from angstrom to nanometer resolution are observed, or analysis of interaction on an atomic level is performed. These approaches are expected to be applied in solving problems in tribology for the ordinary scale environment as well as for the micromachine environment. **[References]** (1)

Microdynamics [マイクロダイナミクス]
[DEFINITION] Dynamics in the microscopic world of micromachines.
[DESCRIPTION] It is considered difficult to describe the dynamic motion of microscopic objects with conventional dynamics because in some cases conventional empirical or theoretical equation cannot be applied. Microdynamics tries to define the dynamic characteristics of motion in microscopic mechanics. **[References]** (1)(6)

Photostrictive effect [光歪効果]
[DEFINITION] The generation of strain induced by irradiation of light.
[DESCRIPTION] The current theory of the photostrictive effect holds that the irradiation of light (ultraviolet rays) on an asymmetric piezoelectric ferroelectrics produces an electric field by the photovoltaic effect, and it causes a mechanical distortion of the material by the piezoelectric effect. A common material that shows the photostriction is PLZT. **[References]** (4)(8)

Piezoelectric effect [圧電効果]
[DEFINITION] The generation of an electric field caused by dielectric polarization in crystals due to strain induced by mechanical stress.
[DESCRIPTION] Since the piezoelectric effect was first discovered with quartz crystals in 1880, various piezoelectric materials including $LiNbO_3$, PZT, PVDF, PT, PLZT and so on have been developed. In such materials the converse effect is observed. These materials are used for sensors and actuators. Examples as sensors are the strain sensor and pressure sensor. And as actuators, the inchworm mechanism consisting of stacked piezoelectric devices and a probe manipulator for scanning tunneling microscope (STM) have been developed. Piezoelectric sensors and actuators are commonly applied in the micromachine-related fields because of the high efficiency and ease of miniaturization compared to electromagnetic devices. **[References]** (3)(6)(39)

Scale effect [スケール効果]
[DEFINITION] Changes of various effects on the objects behavior or the properties caused by the change of the object's dimension.
[DESCRIPTION] The volume of an object is proportional to the third power of its dimension, while the surface area is proportional to the second power. As a result, effect of surface force becomes larger than that of the body force in the microscopic world. For example, the dominant force in the motion of microscopic object is not the inertial force but the electrostatic force or viscous force. Material properties of microscopic objects are also affected by the internal material structure and surface, and as a result, characteristic values are sometimes different from those of bulks. Frictional properties in the microscopic world also differ from that in the macroscopic world. Therefore, those effects must be considered cautiously while designing a micromachine. **[References]** (2)

Preliminary Announcement

The 5th International Micromachine Symposium

October 28 and 29, 1999
at Science Hall, Science Museum, Tokyo, JAPAN

Exhibition 10th Anniversary
MICROMACHINE '99

Exhibition 10th Anniversary MICROMACHINE '99

October 27 - 29, 1999
at Science Museum, Tokyo, JAPAN

The Detail will be announced later.

Pictures on the cover: Winning artworks in the Micromachine Drawing Contests
Tickle alarm, Dentist machine, Ocean survey machine – Angular-robot, and Flower doctor (from top to bottom)

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Takayuki Hirano, Executive Director, Micromachine Center (MMC)
5-F, Niikura Building, 2-2, Kanda-tsukasacho, Chiyoda-ku, Tokyo 101-0048, Japan
Tel: +81-3-5294-7131, Fax: +81-3-5294-7137
Internet Home Page http://www.iijnet.or.jp/MMC/

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