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# Micromechatronics Technology for Wearable Information and Communication Equipment

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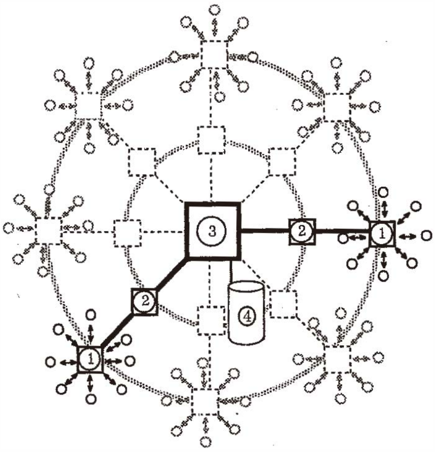
Micromechatronics technology is poised to be an advanced technology for the next-generation mechatronics in the coming multimedia world. Multimedia information and communication equipment are classified into three categories: microcommunication equipment, multimedia storage and communicational mechatronic equipment. The present status of micromechatronics applications in microcommuncation is discussed, as well as the role of microsystem technology in the mobile and wearable computing communications era. Furthermore, some examples of next-generation information devices based on watch technology are proposed, such as a 3-D positioning sensor and an optical nanomemory. A biocommunication network system with such devices in or on the human body is also proposed.

## 1. Introduction

Mechatronics technology is vital to information communication equipment that utilizes mechanical motion, such as high-speed rotation, precision pick-up, and material handling. It is also indispensable in office automation and audiovisual equipment for the technological innovation of key components in achieving larger capacity, higher speed, and portability. Printer heads, magnetic heads, and optical pick-ups are current examples of micromachines. Mechatronics technology is also indispensable in communication equipment for the technological innovation of various high-precision optical parts and components and for interconnection technologies that support key optical communication technologies. Figure 1 shows the relation between communication systems and mechatronics technology.



① Input and Output: Pocket telephone, Nature enviromental sensing, 3-D sensing, Self alignment sensing, Digital micromirror display, Ink-jet printer, etc.
② Transmission: Optical interconnection, 3-D optics, Wireless systems,etc.
③ Switching or Routing: Optical switch, Main distribution frame, etc.
④ Mass Storage: Disk memory, Optical nanomemory, Atomic (probe) memory, etc.

Fig. 1. Micromechatronics technology related to communication network systems.

The information from an input terminal (1), such as a telephone, computer or environmental sensor, passes through transmission lines (2), and reaches the switching system (3). Various multimedia information is switched here and sent to output terminals (1) through transmission lines (2). Finally, the input and output terminals are connected. This is the typical case of communication. However, the input and output terminals can sometimes be directly connected by private lines. In these networks, information and communication equipment have important roles in accomplishing each function: (1) input & output (2) transmission (3) switching and (4) mass storage.

General trends of the mechatronics systems described in refs. (1) and (2) focus on the information communication field, with chronological emergence of new technologies. In this article, the micromechatronics technology is considered to be the advanced technology for the next-generation mechatronics, to meet the demands of wearable computer devices. The present status of micromechatronics applications in the microcommuncation, as well as the role of microsystem technology in mobile and wearable computing communications devices are discussed.

## 2. Multimedia Information and Communication Equipment

On the basis of advanced technologies in the fields of information, semiconductors, optics and mechatronics, conventional communication systems, such as telephones and data transmission, have been revolutionarily advanced and have exhibited dramatic economic growth.

Thus, in multimedia equipment integration for next-generation devices, efficient design and construction are required to enable combination of electronics, mechanism and software resources on the macroeconomic scale. We call this the design of mechatronics systems.

Multimedia information and communication equipment are classified in three categories: microcommunication equipment, multimedia storage and communicational mechatronic equipment, as shown in Fig. 2. The first category includes input & output terminal systems, such as telephones, facsimiles, displays, printers, digital cameras, portable information tools (watches) and sensor tools. The second category includes optical disks, such as compact disk-read only memory, magnetooptical disk, phase-change disk, mini disk, digital video disk and digital memory devices, such as magnetic tape, flexible disk and magnetic disks. The last category includes optical connection parts and devices which are essential in communication systems.

## 3. Microcommunication Equipment

Small and portable information and communication equipment based on telephone and clock technologies are called microcommunication equipment. A typical example of miniaturization can be seen in clock development, which has enabled the development of various portable information equipment.

The system of mechanical clocks was composed of needle drives in which several gears were rotated by main spring power and transducer. In this system, it was very difficult for skilled workers to set up the rotation precisely. On the other hand, the electrically powered clock with electronically driven pendulum, was developed in the United States in the 19th century. In the 20th century, the electronically AC powered clock was invented, which in turn advanced to the transistor clock. In those days, transistors still did not satisfy accuracy requirements. Then, in 1969, the quartz clock was finally invented. It was composed of a crystal oscillator, IC and ultrasmall stepping motor, and realized an immensely improved

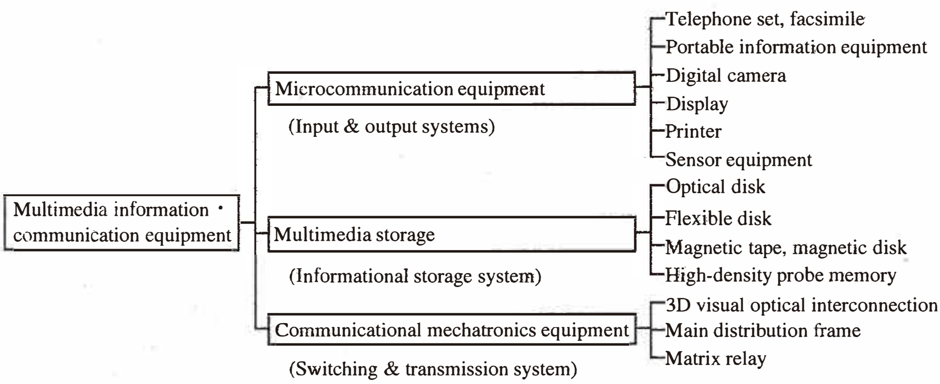



Fig. 2. Multimedia information and communication equipment.

accuracy over that of mechanical clocks. The quartz clock is powered by a battery that drives the quartz oscillation. On application of electric voltage to the quartz, a pure electronic signal arises on the surface through the oscillator combined with the IC.

The limits of miniaturization have been continuously challenged by means of LSIs in quartz clock technology. The electric power consumption of LSIs is small with low-voltage operation. Based on these clock mechatronics technologies, new developments have taken place. Examples of multifunctional information devices are given below.

(1) Health-oriented devices: blood pressure measurement, pulse measurement, calorie calculation.

(2) Business-oriented devices: telephone number records, pocket pager with an FM receiving function.

(3) Amusement-oriented devices: sensible type of joystick installed with a vibrating booster.

(4) Outdoor-oriented devices: terrestrial magnetism sensor, atmospheric pressure sensor, deep-water sensor, temperature sensor and so on.

In the coming multimedia world, such functions as mentioned above will be advanced, resulting in new products. Still, the size and weight reduction of the telephone, which is a typical communications terminal, began with the development of the automobile telephone. Further efforts on size and weight reduction have resulted in the development of the portable telephone, as shown in Fig. 3.[3] The original size and weight of portable telephones were 400 cc and 640 g, respectively. Recently they have been reduced to 81 cc and 69 g. The size and weight reductions are due to various technological developments,

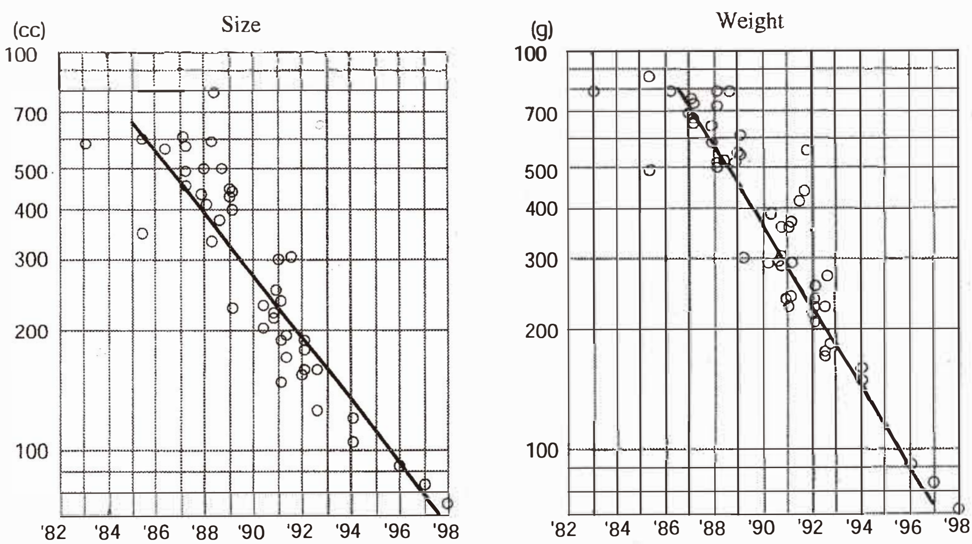



Fig. 3. Size and weight reduction of the telephone.[3]

such as the miniaturization of the inner antenna, one-chip integration of power devices and matching circuits, the monolithic integration of intermediate-frequency amplifiers, and the integration of radio-frequency parts, such as the modulator decoder, enhancement in the performance of various filters, and the use of ASIC technologies for the CPU and peripherals. These are typical microsystem technologies.

## 4. Watch-Size Next-Generation Information Devices

### 4.1 *Proposal of space watch*

People are living in a 4-D world of time and space. On the time coordinate, the measurement device has been miniaturized from sundials to wristwatches, and the wearable information device has been realized. On the remaining 3 coordinates (space), however, the development of measurement apparatus is far behind that of watches; clock-size car-navigation devices have just been developed. A miniature space watch with GPS, magnetocompass, inclination sensor, gyroscope and watch functions will initiate a new era of measurement technology. This will also become a milestone toward wearable computers. The concept of a space watch is shown in Fig. 4. For the measurement of space (position), a gyroscope, inclination (gravity) sensor and magnetocompass will generally be

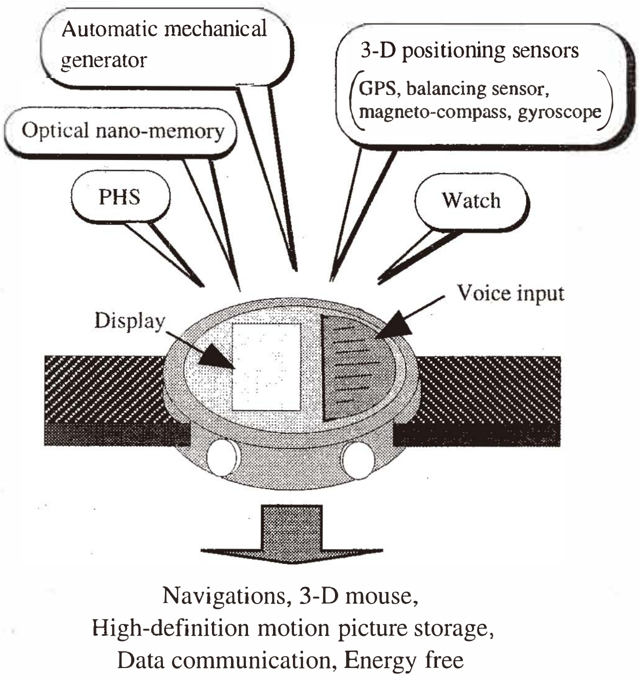



Fig. 4. Concept of space watch.

used simultaneously. If the device is used statically under low-noise conditions like a 3-D mouse, however, magnetic and inclination sensors will be sufficient for measurement. If the device is used for dynamic measurement, on the other hand, a 3-D gyroscope will be necessary (Fig. 5). Since such a device will have larger error than in systems that measure position from an external point, the position of the device should be considered carefully.

### 4.2 *Proposal of watch-size optical nanomemory*

The recently popularized multimedia society requires high-capacity digital storage of high-definition motion pictures. The digital video disk (DVD) memory with 4.7 GB capacity was commercialized in 1996 and it is likely to be a major medium of image storage for the next few years (Fig. 6). In 5 to 10 years, wearable computers will be popularized and watch-size terabit memory will be required for storing high-definition motion pictures and 3-D images. The concept of such a memory is shown in Fig. 7. Its storage capacity should be on the scale of 1 Tbit and its size $2 \times 3$ cm$^2$, and it should use near-field optics for reading and writing data. To realize it, it is necessary to make the read/write (R/W) head follow the data pits of diameter on the scale of 10 nm at a velocity in the range of 10 m/s. Measurement of the 3-D position of the pits without contact or with tapping (light contact) would be required. High-speed nanotracking, precise rotation and near-field W/R heads and media would also be necessary.

### 4.3 *Body-surface communication system*

In wearable computing systems, digital data will be transmitted through media such as clothes, glasses, shoes, and belts. Figure 8 shows the concept of such a communication system. In the space watch concept, the entire system was housed in one device. In this

| | | Usage of geomagnetism | |
|---|---|---|---|
| | | Possible (without noise source or magnetic material) | Impossible (for example, in the steel pipe) |
| Usage of gravity | Possible (quasi-static measurement) | Magnetic sensor + inclination sensor | 2-D gyroscope + inclination sensor or 3-D gyroscope |
| | Impossible (dynamic measurement) | Magnetic sensor + 1-D gyroscope or 3-D gyroscope | 3-D gyroscope |

In the case that high resolution is necessary → gyroscope

Miniaturization → magnetic sensor + inclination sensor or gyroscope

Low-cost → magnetic sensor + inclination sensor

Fig. 5. Environment and conditions of use that affect the construction of balancing sensors.

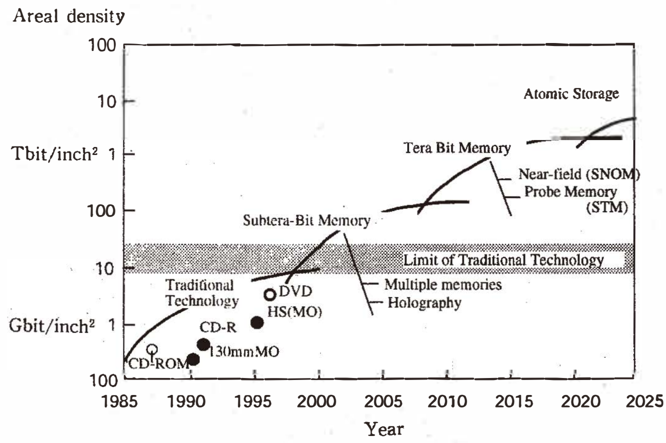



Fig. 6. R/W principle and recording density of optical memories.

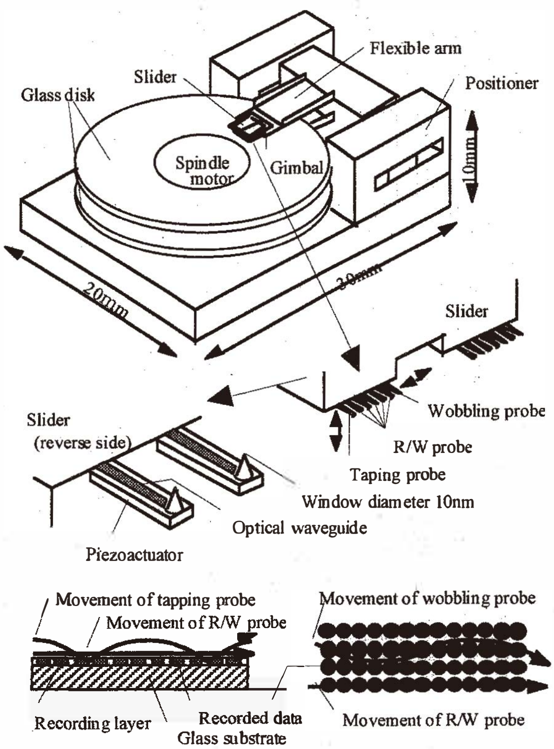



Fig. 7. Concept of watch-size nanomemory.

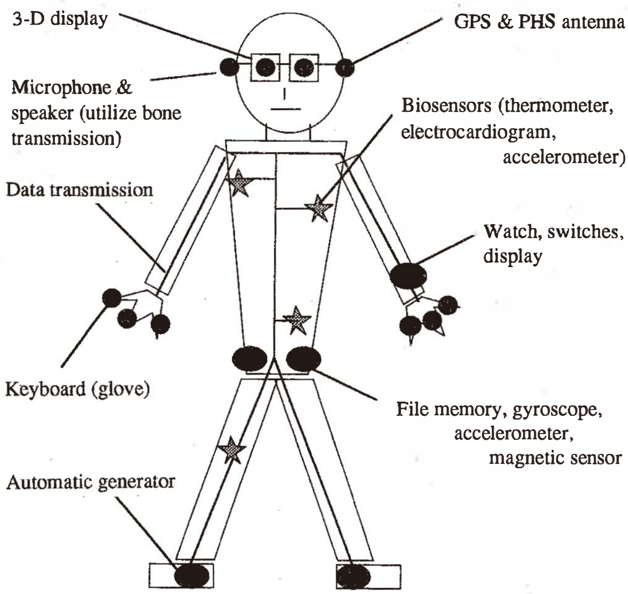



Fig. 8. Body surface data communication system.

communication system, on the other hand, the system components are distributed all over the human body. The concept of a personal area network (PAN) has been proposed by the Media Laboratory of MIT and IBM.

Microsize information devices will be distributed throughout the PAN. Each device is located at an optimal position on the body from the viewpoints of mechanical shock, handling ease and sensor sensitivity. By connecting automatic generators, sensors, input devices and file memories via PAN, walking computing systems will be realized. Also, 24-hour health monitoring, long-term biodata recording and 24-hour position monitoring will be realized with this system.

### 4.4 *Toward bionet system*

In the next stage, wearable computers will become a bionet system which is a fusion of computers and the human body. Toward this system, a data transmission method that uses the human body as a cable is being developed. With this system, it will become possible for chemical sensors installed in the human body to monitor the blood constituents 24 hours and to send data to a remote site by wireless transmission. A data carrier system is the simplest commercialized example of such a system in which an IC chip is installed in the body of domestic animals and ID data are transferred to observation centers by wireless transmission. This system has also started to be used for logistics.

Man has overcome his physical limits by inventing machines, such as reading glasses, binoculars, microscopes, telescopes, hearing aids, telephones, televisions, computers, automobiles and airplanes. In particular, contact lenses, hearing aids and telephones installed directly in the ears fall on the boundary between human and machine. The artificial heart pacemaker is more ambiguous in terms of whether it is a part of a human or a machine. After the installation of an IC chip in a human body becomes commonplace, the next-next-generation information device will be a microdevice that connects the human body with a machine.

## 5. Micromechatronics Technology

In transmission systems, precise alignment, microprocessing, micromeasurement and control technologies will play key roles in automatic optical fiber connection technology, packaging of optical and electrical components, and automatic connection of optical fibers and optical connectors. The maintenance of communication cables has advanced along with diagnostic technologies. It has now become the most important technology for securing communications system stability, reliability and quality, while maintaining reasonable costs, since facilities and systems have become large and complex. In particular, the role of the microsystems technology will be valuable for use in robots that inspect the insides of the narrow tubes where the optical cables for transmission lines will be installed.

In switching and information processing, spatial light modulator technology and holography technology are attracting attention due to their potential for switching laser beam signals.

In storage systems, LSI memories, optical disk memories and magnetic disk memories are currently used. For future systems, as shown in Fig. 6, new technologies, such as multiple memories using holography technology and point magnetic recording (PMR) at the atomic level using scanning tunneling microscope (STM) and scanning near-field optical microscope (SNOM) technologies are currently being studied. In these new technologies, microsystems including microcantilever dynamic technology will be applied most efficiently.

## 6. Summary

Individual technologies such as microactuators, microsensors and microstructures will continue to be studied on the basis of precision engineering. On the other hand, various system needs are being created in a society based on human needs. Generally, it is not easy to satisfy these needs. In Fig. 9, a schematic of such needs is shown. In this example, the system goal of multimedia information systems was chosen as the need, while system technologies indicated in the lower half of Fig. 10 play a crucial role in determining the specifications of the products and their applications.

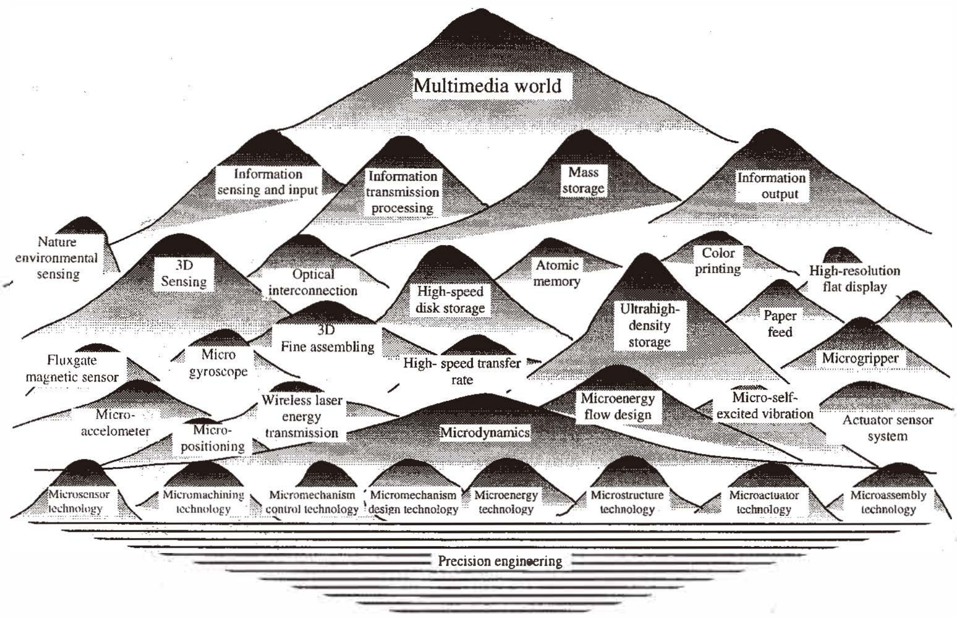



Fig. 9. Multimedia world based on precision engineering.

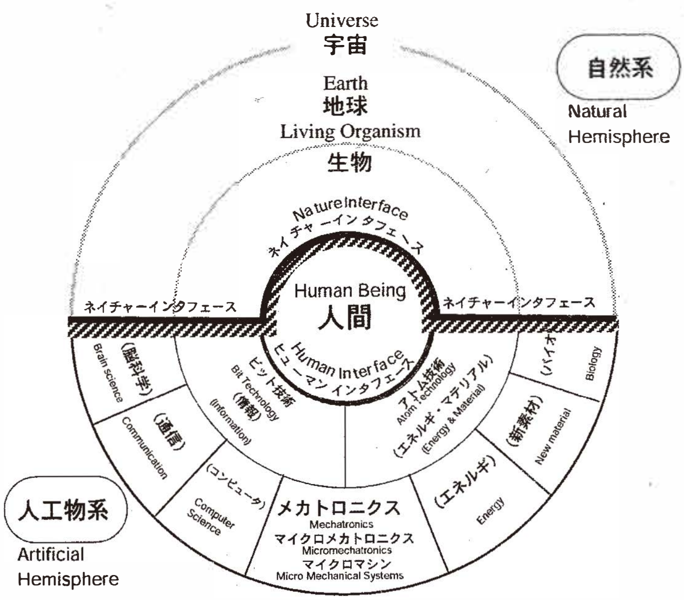



Fig. 10. Human and nature interfaces based on micromechatronics.

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***Kiyoshi Itao*** (Professor of the University of Tokyo, President of the Horological Institute of Japan, Chairman of the Optical Disk Standardization Committee of Japan and Dircctor of Advanced Technology Institute) is currently studying integrated information device synthesis. He received BE., ME., and Ph.D. degrees in precision engineering from the University of Tokyo in 1966, 1968, and 1976, respectively. He joined NTT (Nippon Telegraph & Telephone) in 1968 and conducted research on high-speed positioning of printer mechanisms and developed advanced teleprinters during the first ten years. He has spent time at the Massachusetts Institute of Technology as a research associate, to research wide-band random vibrations.

During the last ten years in NTT, he was a laboratory manager, and developed magnetic tape cartridge-type terabyte storage systems and magnetooptical disk memory systems, and established the development policy of NTT Storage Systems as the Director of the Storage Systems Laboratories. He contributed to the international standardization of 130 mm/90 mm optical disks.

In 1992, he became a professor at Chuo University in the Department of Science and Engineering and started research on microsystem and dynamics for information & communication equipment.

In 1996, became a professor at the University of Tokyo, and is currently studying wearable computer equipment design and microtechnologies for watchtype information & communications devices based on microvibration & microphotonics technologies.