R&D Spirits

Development of Electro-optic Sensors for Intra-body Communications

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Researchers at NTT Microsystem Integration Laboratories have recently demonstrated intra-body communications at practical levels. Such communication within a person's body, which has up to now been difficult to achieve, brings the ubiquitous computing world one step closer to becoming a reality. What kinds of things are possible with intra-body communications? Where are research and development in this field headed? We put these questions to Mitsuru Shinagawa, a Distinguished Technical Member of the Smart Devices Laboratory and developer of electro-optic sensors, a key technology in this field.

Demonstration of intra-body communications at practical levels using electro-optic sensors

—Mr. Shinagawa, could you describe your current research for us?

Well, it concerns the research and development of intra-body-communications technology in which the human body is used as a line for conveying a weak electrical signal. Consider the jolt of static electricity that most of us have felt when touching something metallic like a doorknob. The human body is made up of material that can conduct electricity. And if electricity can flow, why shouldn't we consider the possibility of using the body as a local area network to enable communications? This basic premise of intra-body communications, which is neither wireless nor wired, is an entirely new concept for communications systems.

As computers continue to decrease in size, more and more of them are becoming a part of our daily life. If this process of miniaturization continues and wearable computers become commonplace, we will be able to carry information around with us in a more evolved form of the cellular terminal. At that time, I think it would be natural to expect computers attached to the body to be able to interconnect freely with peripheral computers at high communication speeds. I think intra-body communications will be highly effective here.

—What are some important technical features of this research?

In a typical electronic circuit, a signal travels through a signal line and returns by a ground line forming a path that makes it possible to detect that signal. When attempting to form a circuit in a human body, however, we must remember that there is only one body, which means that there is no return path even if a signal line can be achieved. In other words, the electric field leaks here and there within the body. At the same time, electricity that travels through the human body is intrinsically weak. Conventional technology has not been able to detect signals in such an imperfect state. In response to this problem, I came to use highly sensitive electric-field sensors using electro-optic crystals and a laser beam. An electric-field sensor is a tool for detecting electrical signals as they pass through an electro-optic crystal. It can operate even with imperfect circuits such as those formed in the human body.

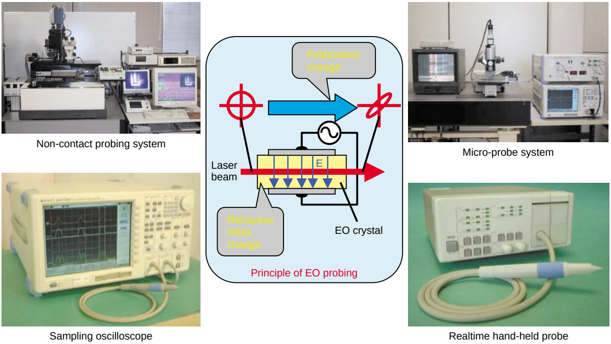

Fig. 1. Electro-optic (EO) probing systems.

This electric-field sensor, by the way, is based on the results of earlier R&D work on integrated-circuit probing equipment (**Fig. 1**). An integrated circuit consists of many signal lines on a very small chip, and a ground line does not necessarily run right next to each signal line. This, and the fact that the direction of electric-field leakage is unknown, led me to develop a sensor that could make measurements under these conditions. Then, I wondered whether a sensor of this type might be able to detect signals in the human body.

However, this was not as simple as it seemed. To begin with, in an experiment applying an unmodified sensor for integrated circuits to the human body, no signals at all could be detected. After investigating this problem from a number of angles, I finally realized that the sensor used for integrated circuits was simply not suitable for measuring electric fields in the human body. It took more than a year, however, to come to this realization. This research was going so badly for a while that, at one time, I even wondered whether the human body could transmit signals!

—How can this technology be used in the future?

Consider, for example, the sequence of actions that occur when I decide to enter a room: I approach the door, stand in front of it, touch the doorknob, and open the door. At this time, my hands and feet come into contact with the doorknob and floor in front of the door, which suggests that this technology could allow the processes of identifying me and unlocking the door to be performed automatically. This is a good example of how unconscious actions can act as a key for conveying human intent. I'd like to point out here that NTT researchers have made a career of determining how to communicate freely at a distance. Of course, this is also an important endeavor, but as we enter the ubiquitous computing age, shouldn't we also pay attention to natural communication at close proximity to ourselves? Intra-body communications would no doubt be extremely useful here. Technologically speaking, such short-range communications could also be accomplished by wireless means, but in congested conditions, the speed of wireless connections can drop dramatically and making a connection itself can be difficult. In contrast, the closed environment of the human body can maintain stable communications.

—How do you think this technology will evolve in three or five years time?

In addition to the door-unlocking example I just gave, other ideas at this stage include exchanging business-card data and inputting it to a PDA (personal digital assistant) simply by shaking hands and automatically downloading information just by touching some object (**Fig. 2**). We can also envision using this technology to display information stored in a pocket computer on a head-mounted display. I can't really say what might be possible in three years time, but in about five years, I would hope to see this technology used for offering some forms of services and gaining a foothold in society.

—How is your research going at present and what are some current issues?

We are currently able to demonstrate intra-body communication speeds of 10 Mbit/s. But to bring the technology to a level that can support services, we must first solve a number of issues. One is device size. While we have been able to develop a device that can be carried around on one hand, it is still too large to be considered "wearable." Another issue is charging a device attached to the body. A battery that supplies power for only one or two hours is hardly sufficient here—power consumption must be reduced. We need to integrate the electronics and improve the sensitivity of the electric-field sensor, the key component here. And in addition to solving these technical issues, it is vital to disseminate information about applying this technology. Since intra-body communications is an entirely new concept, there will probably be some initial difficulty in applying it to business situations even if all technical issues have been ironed out. In this regard, some stern comments were recently expressed at the NTT R&D Forum in the form of "That's very interesting in terms of technology, but what can it do for industry?" To put intra-body communications on the right path toward practical use and enable it to contribute to society, we must give people some idea of its usefulness.

Encountering the "perfect theme" just before changing fields

—What research themes have you been occupied with up to now?

When I was at Tohoku University, I was involved in research for radio astronomy and worked on experiments and numerical analysis dealing with submillimeter-wave frequency response in superconducting

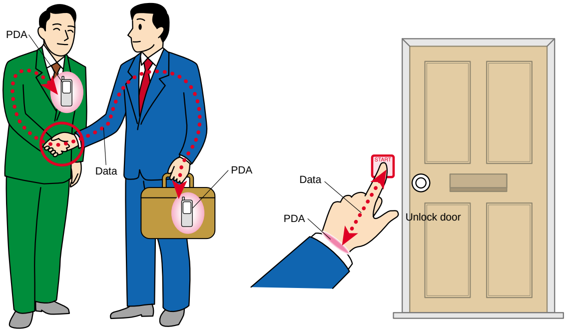

Fig. 2. Application of intra-body communications.

Josephson junctions. Then, upon entering NTT, I became involved with R&D in the field of circuit design. As the need became apparent for accurate measurement and evaluation technologies for developing high-speed integrated circuits, I changed my focus to this research theme. Here, as well, electrical technologies were used at first, but I came to notice that using the same electrical devices for the measurement and evaluation of advanced LSIs and ICs had limits. That is how I came to develop the electro-optic sensor. Because light travels much faster than electricity, I thought that perhaps light could be put to use in measuring all the advanced integrated circuits developed by NTT. I have been involved in the research and development of such technology ever since.

—How did your current research into intra-body communications begin?

When the first phase of R&D for electro-optic sensors was completed and it came time to move on to the next phase, a researcher at NTT DoCoMo happened to ask me whether the electric field of the human body could be detected. I immediately thought of the possibility of intra-body communications. This could not have happened at a better time. Perhaps it was insufficient dissemination of my research results, or maybe that the times were changing too fast, but the usefulness of my electro-optic sensor was not well understood despite the fact that it was a complete working system. I had therefore decided to talk to my superiors about learning new skills. It was exactly at that point that I encountered this somewhat crazy but extremely fascinating idea of using an electro-optic sensor for measuring signals in the human body. Considering that I could apply technology that I had been cultivating for over ten years and might make some contribution to the creation of an entirely new form of communication services, this was the perfect theme. If my conversation with that DoCoMo researcher had taken place several months later, I might now be immersed in a completely different research topic. It feels as if this “chance” encounter was actually fate at work and that I was meant to take on this research. Above all, I was quite overwhelmed by the enthusiasm expressed by that researcher, and it didn’t take me long to make intra-body communications my next research theme. To this day, I still have discussions with him as my research proceeds.

—What is happening in Japan and overseas in this research field?

The world’s first demonstration of intra-body communications took place at MIT in 1996. This was followed, in Japan, by successive announcements from NTT Human Interface Laboratories, Sony Computer Science Laboratories, Matsushita Electric Works, and others. More recently, reports have come out of Washington University and The University of Tokyo. All of those demonstrations, however, used electrical technologies, and in all cases, the communication distances in the human body were only a few tens of centimeters and the communication speeds were only on the order of 10 kbit/s. We feel that our demonstration of intra-body communications using light and achieving speeds of 10 Mbit/s puts us one step ahead in this field. At the same time, the number of patent applications related to intra-body communications is increasing year by year, indicating that various research institutions are beginning to devote true R&D efforts in this direction.

Progress in intra-body communications needs the participation of many researchers

—Are you active in any international organizations and committees?

In May of last year, I presented a paper on this topic at an international conference for the first time, and in July, I presented a dynamic exhibit in collaboration with the DoCoMo researcher. In Japan, I also prepared a dynamic exhibit for the NTT R&D Forum held in October. Until recently, laboratory policy forbade presentations related to this research, and as a result I am still not involved in any international activities. From here on, I think we need to give more presentations in various formats.

—What kind of response did you receive from last year’s presentations?

At the dynamic exhibits, everyone was surprised at seeing the same signal as flowing through a LAN cable also flowing through a human body. Some people were so astonished that they wondered whether the whole thing had been contrived like a magic trick.

Many people were also concerned about the possibility of getting an electric shock, but once they realized that the signal was very weak and that they would feel nothing, they connected and disconnected the signal many times to experience this "magic."

I received several inquiries by mail after these presentations. For example, some people asked whether their components could be used in our electro-optic sensors, which was really a business inquiry, while others were so impressed with the exhibit that they asked about purchasing the equipment regardless of the price. From our side as well, business strategies play a role in our research, and dealing with such inquiries is not a simple matter. We were certainly surprised, though, on hearing such questions.

—Are any joint activities being pursued with business enterprises or research institutions in Japan or overseas?

At present, there are none, but I think partnering is very important. I cannot imagine excluding NTT DoCoMo from such activities, and as long as they are willing, I think DoCoMo will be the first partner. At such time, we will probably select applications that can contribute in some way to the NTT Group. However, that is still years away.

—On the other hand, is there any competition?

As I mentioned earlier, there are research institutions and researchers in both Japan and overseas working on intra-body communications, and I imagine that some of them would be considered competitors. There is some talk, however, that everyone is coming up against walls and even changing research themes. If that is the case, I think that hearing about our progress might convince some of those researchers to try again. I have even heard that some researchers, though continuing in their research, have begun to doubt the feasibility of realizing practical intra-body communications and are becoming dispirited. I hope that our reports give them encouragement. While we are proud to be the leader in this competitive environment at this time, we cannot bring about a major movement in this field on our own. As more people participate, progress in intra-body communications technology will accelerate.

Promoting the use of electro-optic sensors in the world as life work

—Based on your experiences, how do you think NTT is viewed overseas?

During the time that I was researching measurement systems and giving presentations at academic societies, it was often said that "Research at NTT Laboratories targets themes that are feasible and understood." Similarly, some people would say "We want NTT Laboratories to make unbelievable things possible, and to establish fundamental technology that creates new industries." While I could not say that NTT at present only takes on high-risk research, I do think that the research that my colleagues and I are working on matches those expectations, at least in part.

—Where do you think your research is headed in the years to come?

As I mentioned earlier, I believe the field of intra-body communications will encompass two major aspects: R&D of platform technology and the development of usage scenarios. I would like to continue my R&D work in this area with the hope that intra-body communications technology will one day be installed in all kinds of computers including digital home appliances and cellular phones. My dream is that it becomes a standard technology closely connected to everyday life and can contribute to the development of easy-to-use ubiquitous computing services.

At the same time, the origin of my current research activities is, in the end, electro-optic sensors. Encountering the application theme of intra-body communications by chance just when I was thinking of breaking completely from electro-optic sensors tells me that these devices are my chosen field. If I should depart from my current line of R&D, I would like to take on the challenges of electro-optic sensor technology once again. Its application is not limited to the human body. It can be extended to animals and plants and even to buildings and the earth. I would like to analyze the weak fields generated in such materials to see what kinds of information can be conveyed and develop sensor systems that can extract information beneficial for the human race.

—Mr. Shinagawa, what has it been like working at NTT Laboratories?

I cannot say enough about the benefits of working at NTT Laboratories in just a few words. But something of great importance that I have recently come to realize is the great amount of freedom given to researchers. As long as I clearly explained what I wanted to accomplish, I was allowed to take on a new theme within a reasonable range and I was granted suitable resources. Furthermore, when there was something I wanted to know about some technology, there was usually someone in the laboratories working on that research. That made it very easy to conduct research. NTT Laboratories also provides an environment where you can take on a new challenge without the fear of failing. I was allowed to begin my work on intra-body communications with no guarantee of success. Finally, another important benefit of NTT Laboratories is the ability to gather information quickly from around the world as well as to disseminate information quickly and extensively to the outside. I don't think there is another research institution like NTT Laboratories. It's a wonderful working environment that I am grateful for.

Interviewee profile

Mitsuru Shinagawa received the B.S. and M.S. degrees in electronic engineering from Tohoku University, Sendai, Japan, in 1983 and 1985, respectively. In 1985 he joined the Electrical Communication Laboratories, NTT, Tokyo, Japan. He is currently a Distinguished Technical Member in the Smart Devices Laboratory, NTT Microsystem Integration Laboratories, Kanagawa, Japan. His technical areas of interest include timing jitter analysis of high-speed sampling systems, electro-optic sensors, high-precision waveform measurement for ultra-fast electronics, electric field measurement of printed circuit boards, and communication technology for personal area networks. Mr. Shinagawa is a member of IEEE and the Institute of Electronics, Information and Communication Engineers of Japan. He received the Andrew R. Chi Prize Paper Award from the IEEE Transactions on Instrumentation and Measurement in 1992 and the Okochi Memorial Award of Japan in 1997.