By Utilizing the "Swing-by Model," We Can Convert the Environment around Us to a Source of Power

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Overview

Japan is a so-called *super-aging society*, with people aged 65 and older accounting for over 25% of its population. The needs for early detection of diseases and care for elderly people living alone at home are increasing, and it is urgently needed to establish high-precision measurement of biological signals and a platform for processing biological information. In the meantime, society is rapidly globalizing. We asked NTT Fellow Shingo Tsukada of NTT Basic Research Laboratories what kind of stance researchers should take as they tackle research in such an era.

Keywords: hitoe, bioelectrode, interdisciplinary research

Taking up the challenges of medical diagnosis, health promotion, and the sports field from the viewpoint and insight of a former clinician

—Tell us about your current research.

My current research involves the application of a sensing fabric called hitoe™ in three areas: medical diagnosis and treatment, sports and health promotion, and safety management and monitoring. On the basis of my experience as a clinician, I have been keenly aware of the need for technologies that help treat diseases that are difficult to cure and technologies for finding diseases faster, so I have been involved in basic research on those themes. As my research progressed, I focused on the bioelectrodes used to connect weak signals in the body to an electronic circuit, and I thought that PEDOT-PSS,* a conductive polymer being studied at NTT Basic Research Laboratories at that time, would be suitable for bioelectrodes. PEDOT-PSS is very fragile when it gets wet on contact with water, and that fragility is a major barrier regarding bioelectrodes used in wet environments. However, we overcame this problem by coating PEDOT-PSS onto surgical silk sutures, so it can now be used for bioelectrodes. After that, in collaboration with Toray Industries, Inc., we replaced the silk fibers with polyester nanofibers (700 nm in diameter), which we developed and commercialized as the sensing fabric hitoe.

Although hitoe has been practically applied, it continues to be researched. Its usefulness will only be realized when it becomes popular. To ensure that

* PEDOT-PSS: poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate)

happens, it is also necessary to deal with it as a business. Since hitoe was developed, wearable products with similar functions—such as smart watches that can measure heart rate—have hit the market one after another, and they have rapidly gained popularity as simple heart-rate measurement devices. However, measurements taken in a person's daily life or when a person is exercising tend to increase distortion, loss, and noise in the measurement data, but using such measurements in medical examinations such as electrocardiograms requires very high precision. Fields that require high-precision measurements that are difficult to handle with such common wearable products are areas in which hitoe is being actively applied.

In collaboration with medical institutions and other partners, we are currently focusing on promoting the spread of hitoe in the medical, sports, health-promotion, safety-management, and elderly-care fields. In the sports field in particular, with an eye on the major event to be held in Tokyo in 2020, efforts to strengthen athletes are underway, and we expect hitoe to be utilized in such programs.

—I heard that you took up the challenge of measuring a race car driver's vital signs during an IndyCar Series race, the highest peak of formula racing in North America.

When it first came out that we wanted to measure vital data of racing drivers, it was half a year before the IndyCar Series racing season started. We had no idea that an IndyCar race takes place in such a harsh environment, and we did not have the necessary information concerning the car, so we were groping in the dark. I made some time between my other tasks and handcrafted a wearable sensor based on a research prototype. However, it looked as if I wouldn't make it in time. I did everything I could by myself from processing the surface of a fireproofing garment to wiring and attaching transmitters. Eventually, I had to go to the site and check it, so I went to Indianapolis. On the international flight there, I sewed the wearable sensor into the garment to be worn by the driver.

We were able to get the cooperation of the famous IndyCar driver Tony Kanaan and some excellent engineers. In addition, we obtained valuable information that could not be understood unless on site. We then went through a series of trial and error experiments, at the end of which, we managed to make it in time for the actual IndyCar race.

A major factor in our success was that the special areas of responsibility of each party were combined skillfully—like the pieces of a jigsaw puzzle—to make the project a success. To be honest, the project would not have been a success if those members were not involved (**Fig. 1**). Although both the level of skills required and the schedule were tough, it was a great collaborative effort. We leveraged this experience to carry out measurements at other motor races, and it seemed that everyone was surprised at the quality of our technology.

What I have reaffirmed through such experiences is the importance of going to the site and working directly on manufacturing. If the manufacturing work is left entirely to others, it will soon become a virtual world with a poor sense of reality. Some people at the factory, including people at our partner companies, are doing hard physical work, while others are coding and solving bugs in programs. If you get involved in the actual work as much as possible, you will understand their hard work, and you will feel the sense of reality of the research itself. Probably because I'm clumsy, I tend to make a lot of mistakes when I try to do things in an easier way, so I inevitably go by trial and error. By going through trial and error, you get to know what processes are time-consuming, and if you fail you can see why.

Interdisciplinary research has become common. Constantly check your competence in a global society.

—You recognize that the world has largely shifted from the conventional style of research.

As for the environment surrounding research, the framework of research has changed dramatically between the 20th and the 21st centuries. Those who can respond to this change are likely to increase their chances of success in the future. If we look back at the state of scientific research from the early 20th century to the middle of the 20th century, it seems that many of the initial important tasks in each field were tackled by a handful of experts. Then, in the second half of the 20th century, applied research and development (R&D) became the main force, and the number of people involved in it increased as the amount of information grew exponentially. Since the time when there were only a few specialists in a particular area who led in that field of specialization, we have entered an era in which the overwhelming amount of information obtained through the collaboration of many researchers does the leading; in other

ECG: electrocardiogram
HR: heart rate

Fig. 1. Initial members and a driver of the IndyCar Series race project with hitoe™ and the results of biosignal measurement.

words, the information itself has power.

In response to this explosion in the amount of information, signal processing that handles a large amount of data—as represented by machine learning—has made remarkable progress, and various fields are facing upheavals. At the same time, interdisciplinary research is advancing internationally at a speed beyond imagination. It is fine for researchers to focus on a single area of expertise in the conventional manner. However, the environment surrounding research has also changed with the times, and it may seem as if it has become difficult to continue research in one area or specific subject for a long period of time. Since we have entered such an era, I think it is important to study themes beyond one's specialized field from time to time and to learn the external situation through cross-disciplinary exchanges. It may become more common to expand one's research area and work across multiple areas.

—It seems that researchers must change their own way of thinking.

I feel that creating something original in today's highly globalized environment is tough for researchers. Immediately after the introduction of hitoe, wearable sensors appeared one after another around the world, and many products similar to hitoe were marketed. However, the boom in wearable sensors has ended, and we have now entered the age of culling of some of them. In this globalized world, as soon as a breakthrough or research result is noticed, rivals—sometimes even challengers from all over the world—emerge.

Future innovations may need to have the impact of changing existing values. Society does not notice the improvement level in which something a little more convenient is made. And even if we struggle to bring a new technology to the world, we don't always taste success. Multiple hurdles must be overcome before we can spread it in society and earn a stable income. With the emergence of rivals and rapid commoditization of technology, we are conducting R&D that focuses on what can only be done with hitoe.

For example, we are promoting a project to apply hitoe in the area of rehabilitation at Fujita Health University Hospital (**Fig. 2**). In this case, hitoe is being used to monitor the status of exercise and recovery from the amount of activity and the heart rate of patients in the hospital. Compared with the monitoring of healthy young people, monitoring of elderly hospitalized patients—who have small pulse signals—is problematic because those signals are difficult to measure with a normal optical-pulse-wave

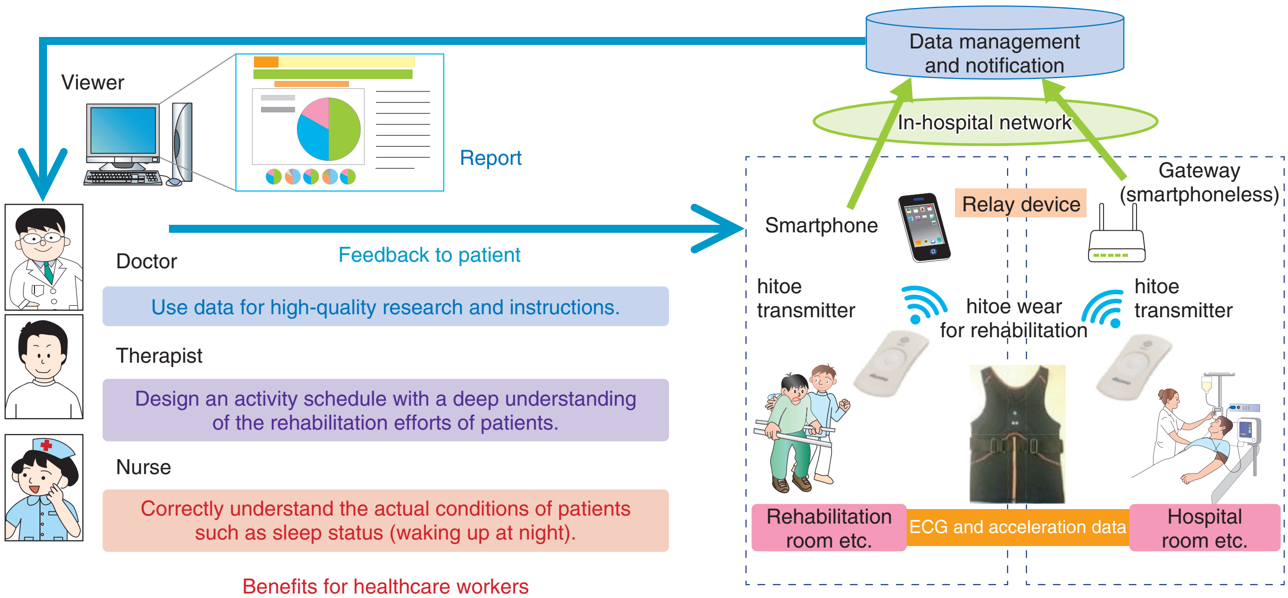

Fig. 2. Activity estimation and data-relay technology for rehabilitation support.

meter. That being said, accurate values must be used as an evaluation index for rehabilitation. Under that severe condition, the strength of hitoe, which measures heart rate from cardiac potential, is utilized. It can meet the expectations of experts, and it is configured so that people who wear it will not feel inconvenienced. For that reason, hitoe is currently in the phase of being optimized for specialized areas that can make use of its features.

The speed and fierceness of competition due to globalization is enough to make researchers cry. When I studied abroad, I felt that research was truly a "global professional society" in a world where research professionals were competing on the world stage just as the world's athletes will compete in Tokyo in 2020. It is thus necessary to train oneself, create an environment, and prepare the necessary conditions to win. However, the style of Japanese researchers sometimes seems to be far from the speedy research style of their Western counterparts. It is likely that some researchers only focus on the topics of the research areas to which they are related and do not pay attention to changes in the environment and society surrounding their research. It is better to evaluate where you are in relation to the global environment by applying objective measures from time to time.

I am trying to recognize the need for that evaluation and to do it myself. That evaluation involves not only evaluating one's output of published papers and amount of knowledge but also focusing on a comprehensive evaluation that includes skills, research styles, and one's philosophy of research. In particular, Japanese workers should maintain an awareness of time and deadlines and also pay attention to work efficiency. Compared with other nationalities, Japanese people, including those involved in research activities, tend to set vague deadlines, so it may be unsurprising that they often work endlessly without setting time limits. Since we lack a sense of completing tasks before key deadlines, we may feel like we are passing time vaguely and will somehow manage because we still have tomorrow.

Only a "handyman" has the chance to grasp real intentions, so go out and meet people!

—What kind of consciousness do you have when confronting such a great change?

I'm aware of my own sense of time, so I try to be as quick as possible. Even if one has such awareness, others do not necessarily have the same awareness. As with athletes at sporting events, it is important for researchers to set a time goal when achieving results, because no matter how good the results are before or after the tournament, they won't be evaluated positively. This is because people (the evaluators) tend to focus on the main event such as a race, rather than all of the practice sessions before and after it. I am always trying to be aware of issues related to time and to finish tasks as quickly as possible.

Because I'm clumsy, I'm often taking detours. Although I sometimes waste time, I try to be aware of how I can work efficiently in a focused manner. And I think above all else, the most important thing is to take action. Whether it is called agile development or not, we do not completely set specifications from the beginning; instead, we plan our R&D activities to better meet the needs of our customers, including those needs concerning technologies and specifications.

In the area of medical care, that situation might be close to the treatment given to an emergency patient on their initial medical examination. In the case of non-emergency medical care, treatment progresses as test results are reviewed, so diagnostic treatment can be performed systematically. In contrast, in emergency care with a patient transported by ambulance, it is necessary to judge the patient's condition immediately from a limited amount of information and test values. Sometimes emergency surgery is required, so it is necessary to be responsive. In regard to R&D as well, I think we should get out into the field as much as possible, meet face-to-face with customers and people in charge, find out their true needs, gather necessary technologies, and start R&D promptly.

Moreover, instead of just listening to requests in the field, we are constantly striving to increase the amount of technology, knowledge, and tools that we can apply so that we can respond promptly to various requests. I must admit though, if I do too much, things get out of hand, and I forget what my specialty is.

Customers may think of me as a "handyman." I think that people feel free to talk to such a "jack of all trades" so they speak their mind. As a result, we can gather more down-to-earth information and get new ideas from the motivation obtained on the spot. And in parallel with the work of gathering the needs of the market, we will work on development while sharing efforts in collaboration with experts knowledgeable in matching seeds. If you work in collaboration with experts in each area, you will be involved with people in more fields, and that involvement will make that work more significant. I always try to put all my effort into solving problems that our customers talked to us about. Sometimes I do too much as a handyman and exceed my workload limit. As a researcher, I try to ensure that I take rests and spare as much time as possible to scientifically explore the subject.

The swing-by model can correct the trajectory of R&D and accelerate it in the direction in which it can proceed.

—How will you conduct research activities going forward?

I have two dreams. One is the development of advanced medical devices. I have a desire to create products that are evaluated positively by experts. For example, I'd like to make a new electrode for cardiac pacemakers with Japanese technology. It is one of the most difficult medical devices to fabricate, and presently it is mostly made outside Japan. The other is to try to detect signs of the onset of sickness and serious symptoms. The first stage of sensing technology has almost reached its goal; however, the second stage, which is signal processing, is very difficult. Although we are struggling at this stage, we are resolutely developing new methods while enjoying the challenge.

—What would you like to say to young researchers?

First, you should build up your basic strength. I think it is important to steadily build up your own specialized area from the basics. For example, in the case of informatics, I think that it is possible to properly evaluate the validity of the currently popular machine learning only by learning the basics of mathematics, statistics, and neuroscience behind the technology and by utilizing that knowledge in practice. I hope that you gain a solid foundational strength that enables you to grasp, analyze, apply, and build things correctly, and gain on-site experience. Second, you must grasp your position on a global scale. Although it is also my personal commandment, receiving objective and international assessments on a regular basis is a very tough but necessary one. To that end, I'd like you to write a research paper, make a presentation at a conference, and interact with researchers. This is an age when it is easy to develop such activities across borders, so I hope that you can go out from NTT and deepen exchanges with other researchers, regardless of your skill in English.

If I may digress, I'm interested in the asteroid explorer Hayabusa. Many planet probes such as Japan's Hayabusa and those of NASA use the "swing-by" principle to reach target planets. Swing-by is a means of navigation to reach a planet; that is, as a spacecraft traverses the solar system and approaches a certain planet, it is accelerated by the gravity and motion of the planet, so its trajectory is altered. Then, by repeating the fly-by with other planets, the spacecraft can travel to its destination planet by expending less energy.

Actually, I thought that our R&D was progressing in the same swing-by manner, so I named it the "swing-by model." When the seed (i.e., a research theme = a small satellite) approaches the area of attraction (i.e., the need = a planet), its trajectory is directed toward the planet (the need), the development is then accelerated by the attraction of the planet, and its trajectory can be corrected (i.e., the directionality of the development is determined). By repeating the swing-by, you can further increase your speed and boost your amount of experience. If you have a distant destination that is slow to reach at first and you cannot reach it by yourself, take advantage of the chance to approach nearby planets, and if you courageously take one step toward your needs (planets), you will be able to accelerate, gain valuable experience (kinetic energy), and get a chance to fly far.

If you are worried that you are not the type of person who'd make the first move, the first step is to try it and start small by yourself. Or if you don't have the courage, you can do it as a hobby. Try your favorite things in your own time. I'm presently searching for a method of biosignal processing. Although I think my pace is rather slow from the viewpoint of a specialized teacher, I'm enjoying increasing my knowledge outside my field as I read textbooks for high school and university students. It's also fun to buy electronic parts and handicraft materials and make things on your own. Being a little adventurous will lead to the first step.

■ Interviewee profile
Shingo Tsukada

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He received an M.D. from Toyama Medical and Pharmaceutical University and a medical license in 1990. He received a Ph.D. in medicine from the University of Tsukuba, Ibaraki, in 2003. He was a visiting researcher at the University of California at San Diego from 2003 to 2005. He joined NTT Basic Research Laboratories in 2010 as a Research Specialist. He has been studying the mechanism and activity control of signal transduction of brain cells. His current interests include the detection of biomedical signals using novel wearable-type and implant-type bioelectrodes based on the composites of conductive polymers with various fibers and textiles. He is a member of the Physiological Society of Japan, the Japan Society of Applied Physics, the Japanese Circulation Society, and the Japanese Orthopaedic Association.