Technologies to Watch in 2019

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Mitsui & Co. Global Strategic Studies Institute
Technology Trends Basic Research Center, Technology & Innovation Studies Div.

Introduction

Every year in January, MGSSI's Technology Trends Basic Research Center looks over almost all technologies in every sectors and picks up some specific technologies to watch in the year ahead from three perspectives. First, the technology must be noteworthy from a medium and long term perspective with the potential to give rise to various developments, rather than merely from the short-term perspective of being put to practical use during the year. Secondly, the technology must have future applications in a wide range of fields, rather than being only applicable to one particular field. Thirdly, the technology must have the potential to be a global game changer that would have a significant impact on society, economy, and industry. It is from the above viewpoints that we have selected the following technologies to pay attention to in 2019.

Brain Machine Interface
— Expanding Industrial Applications of Neural Information Technology —

Yutaka Abe, Technology Trends Basic Research Center

What is Brain Machine Interface?

Brain Machine Interface (BMI) is technology that directly or indirectly connects the brain and a machine to look inside the brain, enhance the functioning of the brain, and treat diseases of the brain. In particular, when the brain is connected to a computer, the technology is referred to as a Brain Computer Interface (BCI). At present, there is no clear distinction between BMI and BCI, and this report uses BMI as a generic term for technologies connecting the brain with machines, including computers.

Why should we pay attention to BMI now? There are three reasons. The first is that since the advent of the 21st century, the advanced Western countries have been making substantial government-led investments in the neural information technology sector. In particular, the US launched The BRAIN Initiative (BRAIN: Brain Research through Advancing Innovative Neurotechnologies) in 2013, and has invested a huge sum in excess of JPY500 billion in private sector companies and universities, and now, five years after its launch, that research is bearing fruit. The second reason is that various small-size BMIs capable of extremely precise measurement of information within the brain have been developed and are being widely utilized even in areas other than the medical field, including neuroscience where they are being used to examine the structure and functioning of the brain, and to understand the causes of brain diseases, etc. Thirdly, Japan is currently a world leader in research into BMI and other neural information technologies. A large number of researchers and engineers in possession of research findings and knowhow accumulated over many years are actively working in this area, and the infrastructure has been developed, led by the Japanese government, to allow for the effective utilization of intellectual assets related to neural information.

As the aging of society progresses in Japan, other advanced countries, and China, how to extend healthy lifespans, prevent dementia and other brain disorders, and reduce medical and other social costs have become pressing issues. The year 2019 is likely to be the tipping point when the social impact and potential of BMI and other neural information technology is once again widely recognized.

Methods and types of BMI

There are two methods of BMI, known as invasive and non-invasive BMIs (Fig. 1). In the invasive method, a hole is drilled in the skull in a surgical procedure, and a BMI is implanted directly on or in the brain. While invasive BMI places a considerable physical burden on the patient, the neural information acquired is very clear, and has a high utility value. In non-invasive BMI, neural information is obtained indirectly from the subject’s scalp. BMIs commercially available on the Internet and elsewhere are the non-invasive type, and while how well the device fits varies depending on the devices, this method is popular as it imposes comparatively little physical burden on the subject.

In addition, there are three types of BMI: input-type, intervention-type, and output type. Input-type BMIs send a signal or energy into the brain. One typical example is a cochlear implant, which is the world’s most widely used BMI. Cochlear

Fig. 1 Types and methods of BMI

Type	Description	Method	Example
Input-type BMI	BMI that transmits signals or energy into the brain	Invasive	Cochlear implants Artificial retinas
		Non-invasive	transcranial Direct Current Stimulation (tDCS) transcranial Alternating Current Stimulation (tACS) Transcranial Magnetic Stimulation (TMS)
Intervention-type BMI	BMI that intervenes in the brain's information processing and signal transmission processes	Invasive	Deep Brain Stimulation (DBS) Depth Electrode
Output-type BMI	BMI that transmits signals obtained from neural and other activity within the brain to a destination outside the brain	Invasive	Electrode implantation (Pinholders, microarrays)
		Non-invasive	Electroencephalogram (EEG) Magnetoencephalography (MEG) Near Infrared Spectroscopy (NIRS)

implants are used to supplement or reinforce the hearing of patients with a congenital hearing impairment or patients who have developed hearing difficulties. They convert sounds picked up by a device fitted outside the body into electrical signals and transmit the signals to the auditory nerve in the brain. This technique uses the signals to stimulate the auditory nerve to restore the auditory function. Other input-type BMIs that are also in practical use are artificial retinas. As with cochlear implants, the external image is converted into a signal that is sent to the optic nerve to restore the patient's visual function.

Intervention-type BMI is a technique used to intervene in the brain's information processing and neural signal transmission processes. Deep Brain Stimulation (DBS), a typical example of interventional BMI, is the most widely used application of the technique after cochlear implants. DBS is used to regulate brain functions when the area in the deep part of the brain that controls body movement is not functioning properly. It achieves this by deliberately intervening in the functioning of the brain by, for example, electrically stimulating the part of the brain affected. There are numerous clinical cases worldwide of DBS restoring movement disorders resulting from Parkinson's disease and similar conditions.

Output-type BMI is a technique for transmitting signals from inside the brain to the outside. A typical example of output BMI is robot control. At present, it is possible to control a cursor on a monitor by neural information alone using an output-type BMI. In a research conducted by Brown University in the US, a quadriplegic patient was able to control a robotic arm. In particular, this technique is expected to be applied to patients with amyotrophic lateral sclerosis (ALS), a condition that causes atrophy and weakness of the muscles.

Thus, BMI is currently being used in medical fields such as cochlear implants and artificial retinas. For the alleviation of the symptoms of Parkinson's disease, and as microminiaturization progresses the focus of attention will shift to new initiatives combining BMI with other technologies such as Augmented Reality (AR) to enhance human senses, and stimulating the brain to improve memory and motor skills, and other benefits. The following section will focus on the application of BMI in areas other than the medical and healthcare sectors.

Promising Areas of Application

ICT sector: Communication using neural information and development of new algorithms

The Silent Talk program (brain-based communication) being developed by the US Defense Advanced Research Projects

Agency (DARPA) seeks to achieve smooth communication and enable reliable command and control amidst the roar of the battlefield, not through vocalized speech, but purely by analyzing neural signals. To be specific, it acquires neural information directly from the soldier's brain by incorporating a BMI and various sensors inside the soldier's helmet. The neural information is then analyzed and converted into an electrical signal which is then sent by a transmitter. In addition, the Intelligence Advanced Research Projects Activity (IARPA), an R&D organization within the US Intelligence Community, is undertaking the MICrONS (Machine Intelligence from Cortical Networks) project. This project aims to obtain a detailed understanding of activities performed by the brain, such as sophisticated cognition, learning, and memory, with a view to eventually developing new machine learning algorithms for utilization in applications such as intelligence analysis and analysis of images from reconnaissance satellites.

Robotics sector: Operation of power assist suits and prosthetic hands using neural information

While the power assist suit made by the Japanese company Cyberdyne is used for work that involves handling of heavy loads, as well as for entertainment and other purposes, the company has now started manufacturing and marketing a suit for patients who are unable to move freely due to neural abnormalities or impaired muscular function. When the wearer attempts to move his/her body, a sensor detects the weak neural signal emitted from the wearer's brain, and the suit operates in accordance with the wearer's intentions by intervening in the motor nerve. The US company DEKA Research and Development also sells a prosthetic arm called LUKE Arm. This prosthetic arm incorporates unique software that operates the robotic arm using information obtained from sensors implanted in the brain. This software enables more accurate and natural control of the arm than is possible with conventional prosthetic devices.

Education & training sector: Optimization of training by combining neural information and AR

The Israeli Defense Forces are conducting simulated combat training using a combination of BMI and AR. Conventional training had required the physical deployment of combat vehicles and the use of large quantities of munitions, but it is now possible to reproduce these conditions in a virtual space. This system makes it possible to substantially reduce the cost of training, so it is being used to evaluate and improve the combat capabilities of individual soldiers by recording and analyzing biological information such as brain waves and heart rate. The US army is also developing Tactical Augmented Reality, and is exploring the possibility of integrating it with DARPA's brain-based communication technology described above. The US company HRL Laboratories is providing training on landing light aircraft to novice pilots using brain wave manipulation. A technique called transcranial direct current stimulation (delivering direct current to the brain to stimulate it indirectly), which is said to have the effect of an increased ability to concentrate, is used when training the novices on landing procedures in a flight simulator, and the performance of the trainees during actual landing improves within a short space of time.

Housing sector: BMI house – operation of electronic control devices in the home using neural information

Various organizations, including Advanced Telecommunications Research Institute International, NTT, Shimadzu, Sekisui House, and Keio University, are collaborating in the development of "BMI House". The BMI used in BMI House is connected to a wireless network and allows users to control a wheelchair and operate electrical household appliances, doors, curtains, lighting, etc. based on their thoughts. It also allows users to convey their feelings, such as pleasure and anger, to their carers. Philips (Holland), in collaboration with Accenture, has developed technology that allows users to control Philips' products and services, such as Philips Smart TV and Philips Hue smart LED lighting, based on neural information to help people with ALS live independently. What is notable about Philips' software is that household appliances can also be controlled with voice or eye commands.

Product development & design sector: Responsiveness evaluation and neuro design

Facebook Media Lab, which is developing neural information technology such as BMI, has formed a team to evaluate advertisements and new products through the application of neuroscience. The aim of the lab is to establish an objective evaluation method making full use not only of neural information, but also physiological analysis techniques such as eye tracking, facial expression analysis, and perspiration. One cosmetics company records and analyzes the brain wave patterns of test subjects in relation to sensitivity information that is difficult to quantify, such as a feeling of moistness or freshness based on neural information, and applies the results to product development. In the same way, the company has been developing products based on the results obtained from neural information relating to the shape, color, smell, and other characteristics of products, and its approach has proven effective. Honda, which is developing robots such as the ASIMO, is also working on an initiative known as "neuro design" that utilizes the characteristics of the brain. Honda has already intentionally designed the front face of its motorcycles to resemble the human face. This is based on the result of BMI-based trials that showed that this design makes the motorcycle more visible to oncoming vehicles.

Future Prospects

While progress in neural information technology such as BMI can be expected to bring various social benefits, there are also risks involved as well. If the technology continues to spread without any form of social restriction, there is a danger of it being used for criminal purposes such as by reading people's thoughts, moving objects in the intended direction, etc. As described above in the section "Promising Areas of Application", neural information technology has many examples of military application. Non-lethal weapons that incapacitate soldiers through direct or indirect brain stimulation have already been deployed. Moreover, the Chinese People's Liberation Army, marked by its substantial expansion, is advocating a new military doctrine, which is translated as "From air and sea supremacy to brain supremacy (brain warfare)", focusing on the brain as its "sixth strategic domain" after land, sea, air, space, and cyberspace, so there is a possibility that it could launch direct and indirect attacks on the brain.

While the military field takes the lead in the application of BMI and other neural information technologies as described above, this technological wave is steadily spreading to the civilian sector and giving rise to innovative new products and services utilizing BMI. For example, technologies that expand and enhance the five senses (sight, hearing, touch, smell, taste) through integration with AR and other augmented reality technologies, and new technological sectors that dramatically improve humans' physical and cognitive abilities through the application of technologies relating to BMI, robotics, and AI are beginning to attract attention.

The brain is said to be the most complex thing known to mankind and has also been called mankind's last frontier. We cannot therefore take our eyes off the future trends in BMI and other innovative technologies that have the brain at the core.

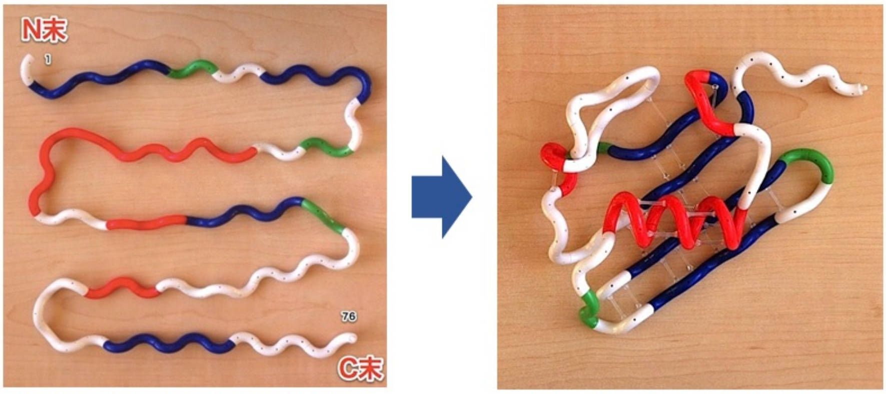
Protein Engineering
— Protein Research Opening up New Possibilities for Agriculture, Food, and Materials —

Satoshi Okada, New Business & Technology Dept., Technology & Innovation Studies Div.

What Is Protein Engineering?

Proteins are made up of various kinds of amino acids linked in the form of a chain, and the amino acid chain only starts to function as a protein when it folds itself into a three-dimensional shape as shown in the model on the right in Fig. 1. Functions of proteins include biological functions, such as nutritional value, medicinal effect, enzymatic functions, and physical and chemical functions, such as solubility, elasticity, plasticity, emulsification, strengthening, and adhesion. Proteins have been used in fields such as medicine, food, and detergents for many years, taking advantage of functions like these.

Fig. 1 Model showing the 3D structure of proteins



Model of amino acid linked in a chain. In this state the chain does not function as a protein.

Model of amino acid linked in a chain and folded into a 3D structure. By forming a 3D structure the protein becomes functional.

Photo source: Website of Prof. Hideki Taguchi, Tokyo Institute of Technology
http://taguchi-hideki.blogspot.com/2015/12/tangle-proteins-building-set_19.html

Protein engineering has been described as a technology to modify the functions of natural proteins, mainly enzymes by clarifying the structure and functions of proteins according to *Biotechnology for Beginners Part I,* Reinhard Renneberg. Recent years have seen an advance in structural analysis techniques such as electron microscopy, X-ray crystallography, NMR analysis, small-angle X-ray scattering (SAXS), and analytical ultracentrifugation (AUC), which has revealed the three-dimensional structures of complex proteins. As a result of this, data on the relationship between protein structure and function has accumulated, and scientists have begun combining this into big data. Professor David Baker of the University of Washington developed a method to utilize this big data to design and produce completely new proteins at will, in addition to making modifications to natural proteins. With technological developments such as this, protein engineering can be said to have entered a new era.

Promising Areas of Application

Protein engineering is already in widespread use in the medical field. Antibodies are proteins that bind to and neutralize pathogens such as viruses and bacteria. To achieve the maximum effect using this mechanism, it is necessary to create a protein with a three-dimensional structure that can bind firmly with the virus or bacteria in a similar way to the relationship between a key and a keyhole. Protein engineering has been used to design and produce proteins with such 3D structures, and more than ten antibody drugs have been developed so far. While protein engineering has been mostly used in the medical field, it is also recently being applied in the agricultural, food, and materials fields. The following paragraphs describe how protein engineering is being used in these three fields.

Agriculture

While synthetic agrochemicals have made a substantial contribution to improvements in agricultural productivity, as interest in global environmental issues has increased, there has been growing concern about water pollution and soil contamination caused by synthetic agrochemicals. The importance of using such chemicals properly has become frequently pointed out since the 1990s. In recent years, the harmful effect on consumers of residual agrochemicals in crops has also come to the fore. The widely used herbicide Dicamba is also raising concerns over environmental pollution and damage to health. The US agrochemical and seed giant Corteva Agriscience, in collaboration with the US company Arzeda, which was established by Professor Baker mentioned above, has successfully developed Dicamba degrading enzymes. The enzymes were designed according to the 3D structure of Dicamba to achieve effective degradation. Arzeda focuses on proteins with an insect repellent effect contained in the neem tree, and designs proteins that have enhanced effect. It conducts R&D of a technology to produce the protein using yeast. While bio-agrochemicals that use substances produced by living organisms are generally considered to be less effective, their effectiveness is being enhanced by modifying their 3D structures using protein engineering.

As well as agrochemicals, Corteva and Arzeda are also utilizing protein engineering to develop seeds for crops such as corn. Arzeda is designing enzymes to improve crop yields while Corteva is developing new plant strains in which those enzymes are expressed.

Food

In the food sector, companies developing sugar substitutes and companies developing products utilizing the physical and chemical functions of proteins are emerging.

(1) New sweeteners

While the composite plant stevia is widely used as a natural sweetener, it is often considered unsuitable, particularly for use in soft drinks, because of its sweet aftertaste. In July 2018, leading UK food ingredients company Tate & Lyle announced that it has developed a stevia-based sweetener TASTEVA©M in collaboration with the US company Codexis, a developer of software for designing protein structures. TASTEVA©M is a low-calorie sweetener with a taste close to that of sugar produced by modifying stevia through an enzymatic reaction. Codexis designed the enzyme that changes the structure of the stevia extract to make it taste more like sugar.

Israel's Amai Proteins is another company that uses protein engineering to develop sweeteners. Amai Proteins' CEO

Ilan Samish spent many years designing proteins using computers at Israel's Weizmann Institute of Science. Fruits such as miracle berry that grows in the shade of tropical jungles contain sweet proteins, but these proteins are destroyed by heating and other processes. By analyzing the structure of natural sweet proteins and altering the amino acid composition of the part destroyed by heating, Amai Proteins developed a sweet protein that remains stable even when heated. Amai Proteins receives backing from The Kitchen, an Israeli food tech incubator, and is also considering collaboration with the global companies PepsiCo of the US and Danone of France.

(2) Product development utilizing physical and chemical functions

The US startup JUST manufactures egg-free mayonnaise, dressings, cookie dough, and scrambled eggs. What is noteworthy about JUST is that it is actively introducing big data analysis. It analyzes the structures of numerous types of plant proteins and builds big data on their physical and chemical functions. JUST employs data scientists from companies such as Google and develops protein materials with the desired properties by combining multiple proteins based on its analysis of big data. This may lead to the future development of new products other than egg substitutes.

Materials

Three startup companies Bolt Threads (US), Spiber (Japan), and AMSilk (Germany) possess technology to produce proteins contained in spider silk using genetically modified Escherichia coli bacteria. Many kinds of spider silk proteins are stronger than steel and lighter than cotton. These companies possess data on the genes of many types of spider and on the physical and chemical functions of the proteins produced by those genes. Using this data, it is possible to create materials from proteins for the desired purposes. Bolt Threads is working with leading UK fashion brand Stella McCartney and both Bolt Threads and Spiber are working with the US outdoor clothing company Patagonia with a view to developing original products for the apparel market. In September 2018, AMSilk announced that it is developing a lightweight composite material for aircraft with Holland's Airbus.

The US startup Modern Meadow is developing protein materials as alternatives to natural leather such as alligator skin and cowskin and sheep hides. The company grows proteins using genetically modified yeast, such as collagen, and then processes the proteins into a material with the texture and durability of natural leather. One of the company's strengths is the ability to process proteins using technology borrowed from material science. The company developed a bioleather called Zoa using a 3D printer, and a prototype t-shirt made from this material was exhibited at the Museum of Modern Art in New York in October 2017. Also, in March 2018, Modern Meadow announced that it will partner with Evonik Industries, the German specialty chemicals giant, in order to scale up operations.

Future Prospects

Further advances in the medical field

New business utilizing protein engineering has already begun to appear. While it is certainly worth watching closely, there are still unresolved problems in scientific terms. As described at the beginning of this section, proteins consisting of amino acids linked in the form of a chain are folded into a three-dimensional structure, but the mechanism by which these 3D structures are formed is not fully understood. For example, even though a 3D structure may be formed in a test tube, it may not be formed inside a cell. If the mechanism by which a 3D structure forms can be explained and controlled, it will be possible to create more effective proteins. Research into the mechanism of the formation of these 3D structures is underway in the medical field for the purpose of understanding the pathogenesis of diseases such as Alzheimer's and Parkinson's. This technology is also expected to be transferred from the medical field to the agricultural, food, and materials sectors.

DIY Bio

The materials developed using protein engineering in the food and materials sectors possess physical properties never seen before. Accordingly, a prototype development model approach whereby manufactured prototypes are used and improvements are made based on feedback from the users is likely to be effective.

The activities of DIY bio communities are attracting attention in the frontlines of prototype manufacturing. DIY bio is an expanding movement, mainly in Europe and the US, in which individuals and small and medium-size companies undertake R&D in biotechnology in co-workspaces and other shared venues. Many of the startup companies mentioned in this report utilize such DIY bio communities. In such a set-up, numerous prototypes can be produced worldwide utilizing protein engineering, which might give rise to new business opportunities.

Haptics
— Emergence of 5G and Evolution of Actuation Technology Heralds the Practical Application Phase —

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What is Haptics?

Human senses are classified into the five senses of "sight, hearing, touch, smell, and taste". In the IT world, sight and hearing have been used as the method of user interface (UI), but in recent years, the sense of touch (haptics) has been attracting attention in various technological contexts.

The technique of digitalizing these sensations is known as sensing, and the technique for accurately reproducing these numerical values is known as actuation. For example, in the case of hearing (sounds), the sensing is performed by a microphone and the actuation is performed by a speaker. In the case of touch, the sensing is performed using a pressure sensor or a heat sensor. While its actuation is achieved mainly using a contact-type system in which the sense of touch is reproduced through vibrations produced by a motor or a piezoelectric element, use of non-contact type ultrasonic wave systems has been growing in recent years.

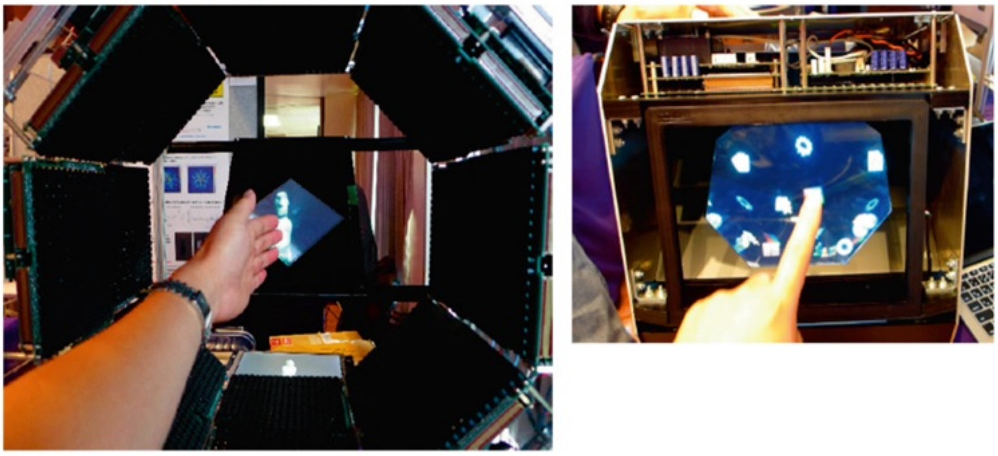
In the case of smell as well, efforts are underway to develop technology to easily incorporate the element of smell in VR (Virtual Reality). This is achieved by attaching a device to the VR headset, which generates the optimum smell synchronized with the virtual world. There are also companies appearing that formulate tailor-made smells and provide them in the form of cartridges used with VR headsets. While development of taste sensors has been underway for some time, the evaluation of tastiness also concerns evaluation by the senses of smell and sight. Recent years have seen some efforts to quantify this data and utilize it to develop beverages and food.

Promising Areas of Application

Utilization of haptics as feedback for gesture UI

Gesture input, which is available without physically touching a screen or buttons, is already being used at medical institutions from a hygiene point of view. Its use is also being considered for ATMs and similar devices from a security point of view, and for air-conditioning, audio, and other devices in automobiles to enable hands-free control. However, one drawback of gesture input is that since it is a non-contact method, there is a lack of feedback to confirm that the control has been surely performed. Research is underway to equip a haptic feedback function utilizing ultrasonic waves. Professor Hiroyuki Shinoda and his colleagues at the University of Tokyo conducted research that successfully reproduced the sense of touch by controlling the output and phases of ultrasonic waves produced by an array of ultrasonic elements (Fig. 1). The UK company Ultrahaptics has also succeeded in developing a similar device that can be used for practical applications and is exploring its use for automotive UIs and similar applications.

Fig. 1 Tactile reproduction technology using ultrasonic waves developed by Professor Hiroyuki Shinoda and colleagues at the University of Tokyo

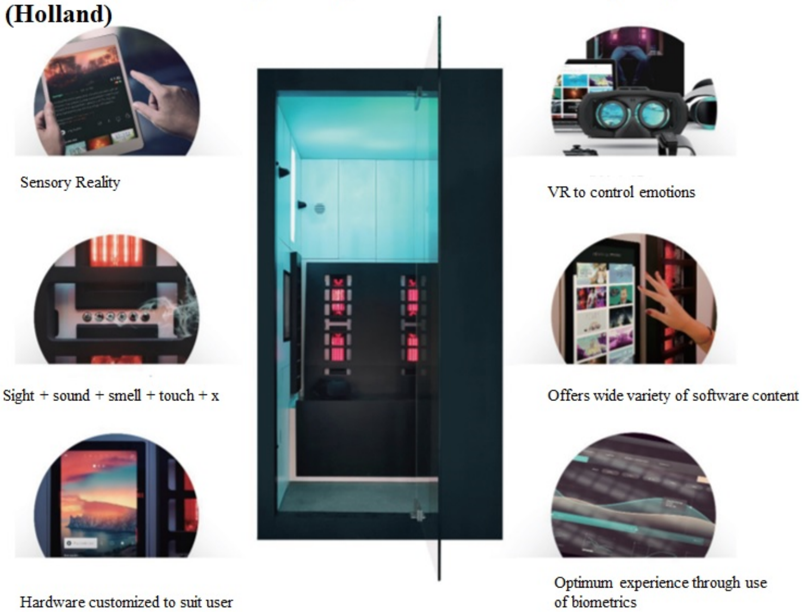


Source: Nikkei Electronics April 2018 issue

Application to VR (interaction with the virtual world)

In the realm of VR, sight and sound have been used to interact with the virtual world. Research is underway into the use of touch to make the user experience even richer. The introduction of contactless actuation technology using ultrasonic waves is also being considered for these purposes. As one example of application, Haptic feedback functions are expected to be introduced in areas such as 3D games and experiential entertainment. The Dutch company Sensiks has developed a box-type device that allows the user to experience a virtual space not only with the sensations of sight and sound, but also with those of touch and smell (Fig. 2). By reproducing sensations as subtle as the heat of the sun, the feel of the wind, and the smell of a meadow, users can now experience the sensations of a virtual space more realistically.

Fig. 2 VR Pod incorporating touch and smell developed by Sensiks (Holland)



Source: Website of Cornes Technologies

The US company VAQSO has released a kit that allows the user to enjoy five types of scents in a virtual space when it is attached to a VR headset (Fig. 3). An API (Application Programming Interface: specifications that facilitate the software development process) for the Unity, which is the standard development environment (software) for VR, is also provided, and developers can create olfactory content that is coordinated with the senses of sight and sound to be used in a virtual space. The company offers a service to blend and sell scents in accordance with the customer's request.

Fig. 3 Scent generating device for VR developed by VAQSO (US)

Source: VRonWEBMEDIA, posted on November 21, 2018

The use of tactile reproduction technology is also attracting attention in the EC (Electronic Commerce) world. While a growing number of virtual stores utilizing visual and auditory VR have appeared, it has not been possible for customers to feel the texture of products, which is particularly important for items such as apparel. At present, haptic technology has not been put to practical use in the EC world because of the limitations of ultrasonic techniques in terms of strength and resolution. However, as the technology improves going forward, it will also be possible to reproduce the feel of products to a certain extent, and VR should become more widely used in EC.

Teleoperation

When people perform delicate tasks they usually rely on their sense of touch to make adjustments in the force that they apply. This sensation is referred to as kinesthetic sensation. In teleoperation, this kinesthetic sensation is integral for improving the accuracy and efficiency of the operation. Researchers at Keio University are conducting research and development into the precise sensing required to reproduce kinesthetic sensations and the actuation technology for feedback, which will enable delicate operations to be performed remotely. Motion Lib, a venture company launched by Keio University, has developed kinesthetic technology that enables low-cost force control by estimating the load force applied to a motor, and it is manufacturing and marketing this technology.

Further, progress is being made in the development of technology for improving the efficiency of work by accurately sensing myoelectric potential and brain waves. It was previously considered difficult to use brain waves, in particular, because they are extremely weak, but moves are now underway to make practical use of brain waves by means of pattern recognition technology using deep learning. These technologies are known as BMI (Brain Machine Interface).

The key to the advancement of teleoperation is 5G (5th generation mobile communications system) technology, which will commence operation as a commercial service in 2019, mainly in advanced countries. With 5G, the network delay is expected to be less than one millisecond, and this will make it possible to transmit haptic feedback with an extremely small delay. Reducing this delay is essential for realizing accurate operations with a natural feel, and telecommunications companies such as NTT DoCoMo and Softbank are conducting trial experiments into the practical application of teleoperation.

Business areas where teleoperation will be actively used in future include medicine (surgery), manufacturing, construction, and customer service. Against the backdrop of a shortage of doctors and a decrease in population, demand for teleoperation in the medical sector is expected to increase. The "da Vinci" robot, created by the US company Intuitive Surgical, is a typical example of a conventional surgical assistant robot, but due to the absence of a haptic feedback function, accidents have occurred, including cases where damage has been caused to organs adjacent to the site of the operation. It is believed that a haptic feedback function would reduce these kinds of accidents. The Japanese surgical assistant robot startup Riverfield is developing a robot that transmits tactile sensations to the surgeon's hands, and it is aiming to bring it to market in 2020.

In the manufacturing industry, it is possible that work currently being performed directly by workers in factories will be taken over by robots operated remotely by an operator. Robots of this kind are called telexistence robots. Haptic technology is indispensable for performing tasks in manufacturing such as gripping objects, and it is believed that the development of haptic technology and the roll-out of 5G will promote the introduction of telexistence robots in the manufacturing industry.

Similar developments are also being considered in the construction industry. NTT DoCoMo and Komatsu are conducting experimental trials on teleoperation of heavy machinery (Fig. 4). While the intention is to take advantage of the low latency of 5G to control with an accuracy of several centimeters, haptic feedback technology is still likely to be

Fig. 4 Power shovel teleoperation system developed by NTT DoCoMo and Komatsu

Source: Impress K-Tai Watch, posted on January 24, 2018 essential for such precise teleoperation. Studies are currently being carried out into the possibility of replacing humans with humanoid robots at construction sites where operations tend to be dangerous, and companies such as Japan's MELTIN MMI are developing high output actuators capable of replacing human workers. The work performed in the construction industry is complicated, and there are still many tasks that it would be difficult for an autonomous robot to perform. That is where telexistence robots come in, and they are expected to put into practical use in future.

Since customer service at restaurants and commercial and other facilities is an area where it would be difficult to replace people with autonomous robots due to the subtle interpersonal skills required, it is also a potential area for the introduction of telexistence robots. Work such as waiting at table and delivering goods involves handing things over to people. Since tactile force is important and haptic feedback is necessary, the demand for telexistence robots equipped with haptic functions is expected to increase. Among other things, the introduction of telexistence robots will make it unnecessary for workers to commute and to make it easier for people with disabilities to work from home.

Future Prospects

Improving UX by adding haptics to VR

Enabling interaction with the virtual world through the sense of touch in addition to the conventional VR user experience (UX) centered on sight and sound allows the user to become more immersed in the virtual space and improves the UX. Accordingly, experiential entertainment content, for example, can be modeled to include the sensations of touch and smell in addition to sight and sound, and products that give the user a richer experience are expected to show growth in the future.

New working environments free from the constraints of location

While many of the tasks performed in areas such as medicine (surgery), manufacturing, construction, and customer service have relied on the sense of touch, owing to the reduction in communication latency resulting from the advent of 5G and the development of tactile sensing and actuation technology, we are now entering an era in which tasks can be performed remotely. In a future where various types of work can be performed remotely, the limitations imposed by physical location will no longer apply. This will give rise to flexibility in the working environment and is likely to gradually increase the range of occupations for which teleworking is applicable. Moreover, when combined with crowdsourcing, it will be possible to secure labor more flexibly. This has the potential to drastically change the way people work around the world, including the possibility of workplaces transcending national borders, and these are future trends that should be paid attention to.

Summary of Technologies Highlighted in 2018 (Quantum ICT/Omics Analysis/Materials Integration)

Following is a brief summary of the subsequent developments of quantum ICT, omics analysis, and material integration, which we introduced in our report entitled *Three Technologies to Keep Eye on in 2018* published in January 2018.

Quantum ICT

Quantum ICT is a generic term for technologies that utilize the physical properties of quanta such as quantum computers, quantum cryptography, and quantum sensors to achieve breakthroughs in areas where existing ICT is reaching a functional limit in terms of its ability to improve speed and performance. In our January 2018 report, we predicted that 2018 would be the first year of the quantum ICT era.

As we predicted, 2018 became the first year of the quantum ICT era. Quantum ITC began to attract rapid attention, with a variety of developments taking place around the world. In the US and China, the battle over the next-generation technological supremacy, such as 5G (5th generation mobile communications system) has grown increasingly fierce amid their trade friction, and this competition is also underway in the field of quantum ICT development, involving both states and private organizations. The Chinese Academy of Sciences is investing 76 billion yuan in constructing a National Laboratory for Quantum Information Sciences in Hefei, Anhui Province (to be completed in 2020), and has already established an ICT research facility with Alibaba. Baidu also opened its own quantum ICT research facility in March 2018, and Tencent also looks set to follow on the heels of its two rivals. In particular, Alibaba, second only to IBM, has developed an 11-qubit quantum computer (February 2018), and is planning to invest as much as USD15 billion in cutting-edge areas such as quantum ICT. This trend of a vigorous push to develop quantum ICT through public-private partnerships in China has spurred the US to act, and the National Quantum Initiative Act was submitted to Congress in recognition of the need for a national strategy for the quantum ICT field. The act was signed into law on December 25, 2018 by President Trump, setting up a plan to invest USD1.2 billion over a five-year period starting in 2019. The EU is also implementing plans to invest 1 billion euro over 10 years in its Quantum Technology Flagship initiative, while Japan has also formulated “New Measures to Promote Quantum Science Technology.” In particular, Japan is currently producing unique results under the Cabinet Office’s Impulsing Paradigm Change through Disruptive Technologies Program (ImPACT), including allowing public access via the cloud to a quantum neural network computer developed under NTT’s leadership. As such, the advanced countries are stepping up their efforts in quantum ICT R&D. This is expected to lead to a dramatic expansion and enhancement in ICT overall in future, along with the emergence of a wide range of disruptive innovations. (Yutaka Abe, Technology Trends Basic Research Center)

Omics Analysis

Omics analysis is a technology for conducting exhaustive examinations using a variety of biomolecular data, and it is attracting attention in the development of preventative medicine and therapeutic drugs. Our 2018 report noted that research and development of new drugs by pharmaceutical companies using omics analysis and its utilization in the field of examination for precision medicine will gain momentum.

In January 2018, AbbVie (US), Alnylam Pharmaceuticals (US), Biogen (US), AstraZeneca (UK), and Pfizer (US) joined the existing consortium of three companies, The Regeneron Genetics Center (a subsidiary of Regeneron Pharmaceuticals of the US, a world leader in omics research), Biobank[1] and GlaxoSmithKline of the UK, which was established to conduct research into omics in the field of drug development. Several omics-related developments were seen in this area, including the formation of a partnership between Iceland's deCode Genetics, a subsidiary of the US company Amgen, and the omics analysis company SomaLogic in December 2018. Utilization of omics analysis in the development of new drugs is expected to accelerate further through such collaborative research efforts. In the examination field, the application of liquid biopsies (i.e. procedures that allow genes and other molecules to be examined simply and conveniently from a blood sample) to precision medicine is gaining momentum, and partnerships have been formed one after another between pharmaceutical companies and companies offering liquid biopsies. In January 2018, US pharma giant Bristol-Myers Squibb partnered with Personal Genome Diagnostics of the US to achieve precision treatment with its cancer immunotherapy drug Opdivo®. In Japan, too, in February 2018, the National Cancer Center launched a trial of a treatment for colorectal cancer with Guardant Health of the US. Furthermore, in October 2018, St. Luke's International University and Shimadzu Corporation announced the identification of biomarkers for non-alcoholic fatty liver disease through omics analysis. In addition, AmoyDX's liquid biopsies has been granted approval to diagnose for the treatment of lung cancer in China. In future, interest is expected to increase not only in precision cancer treatment, but also in the area of early stage diagnosis, and omics analysis is an area to which close attention should be paid. (Takako Kato & Mika Kinoshita, New Business and Technology Dept., Technology and Innovation Studies Div.)

Materials Integration

Materials integration is defined as an integrated materials development support system that utilizes information science to explore new materials as well as to predict performance, changes in performance over time, and other characteristics of materials with a high degree of accuracy. Our 2018 report noted that while the knowledge accumulated by US and European chemical companies is being divulged as corporate divestment proceeds, Japanese companies that have maintained their independent structure as general chemical companies and kept hold of their knowledge will demonstrate their presence with the development of this technology.

The year 2018 saw increased activities in R&D into multi-materials for automobiles and other transportation equipment, which our report cited as a potential area for the application of materials integration. In Japan, which

[1] UK Biobank: A gene bank for medical research purposes in the UK.

possesses strong technological competitiveness, the New Energy and Industrial Technology Development Organization (NEDO) adopted the "Development of Materials Integration Utilization Technology for Performance and Lifetime of Magnesium Materials" as a research theme to proceed with development during the research period running from FY2018 to FY2022. Specifically, NEDO has started developing a calculation module for predicting the fatigue properties of flame-retardant magnesium alloys and building a database of the fatigue properties, lifetime, and other characteristics of these alloys. NEDO has also adopted three related research themes: "Development of Innovative Design Technology for Multi-material Auto Body Weight Reduction," "Development of Corrosion Behavior Analysis Technology for Ultra-high Strength Steel Sheets" and "Development of Hydrogen Embrittlement Behavior Evaluation Technology for Ultra-high Strength Steel Sheets." Each of these research themes are concerned not only with the structure and properties of the materials themselves, but also delve into the performances and processes required for advancing materials integration, looking at the practical application of these technologies. Our report noted that materials integration would become a powerful tool for improving the international competitiveness of Japanese material technology, and 2018 certainly proved to be a year in which Japan made great progress in building that powerful tool. (Manabu Nagashima, New Business and Technology Dept., Technology and Innovation Studies Div.)