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Optical Lattice Clocks Started Real Contributions to Precision Measurements

—Rapid evaluation of optical frequency at the 10^{-15} level—

IDO Tetsuya

Planning Manager, Strategic Planning Office, Strategic Planning Department

After completing a doctoral course and serving as Researcher at JST-ERATO, Research Associate at JILA (NIST/University of Colorado), and as a JST-Sakigake Researcher, IDO joined NICT in 2006. He was a Senior Researcher of Space-Time Standards Laboratory, Applied Electromagnetic Research Institute until October 2012. Since completing a doctoral course, he has been engaged in Sr-atomic laser cooling and its application in optical lattice clocks, and also later in research of vacuum ultraviolet light generation that utilizes frequency comb technologies. Ph.D. (Engineering).

Background

NICT sets and transmits the national frequency standards, and disseminates Japan Standard Time as well. When we have a reference frequency obtained from a time calibration signal, etc., we can calibrate frequency by taking a comparison of the standard time calibration signal and the frequency we want to calibrate. Disseminating frequency standards is one of NICT's missions*1 as described above. Precise frequency standards are generated by atomic clocks. Currently, seconds and their reciprocal frequencies are defined based on the electromagnetic wave corresponding to the energy difference between the two lowest energy states of cesium atoms (approximately 9.2 GHz). At NICT, we have been developing atomic clocks using cesium atoms and made this electromagnetic wave as our benchmark for seconds. Although 16-digit precision is starting to be derived with state-of-the-art cesium atomic clocks, this precision is unfortunately obtained only after over 3 hours of ongoing measurements and taking the average. Hence, we can only measure frequencies over a long period of time that are stable and whose values do not fluctuate. Building an atomic clock with frequency in 5-digit high-optical range (approximately 400 THz) has enabled precise 16-digit measurement by signal integration within 100 seconds, and moreover, the realization of 18-digit precision is expected. Optical lattice clock system originating in Japan and single ion optical clock system originating in western countries are being extensively studied at research institutes around the world. At NICT, a lattice clock based on strontium (Sr) atoms (uncertainty of $5×10^{-16}$, Figure 1) and an ion optical clocks based on calcium ion (Ca^+) (uncertainty of $2×10^{-15}$, Figure 2) are studied. In our recent research, we used a Sr optical lattice clock that already had received 16-digit credibility—1 second in 65,000,000 years— as a frequency reference and measured Ca^+ single ion optical clock-generated frequency with 15-digit precision. This means that we conducted other optical frequency calibrations with the Sr optical lattice clock as a standard, which marks the beginning of a forthcoming era in which frequencies in the optical range are standardized.

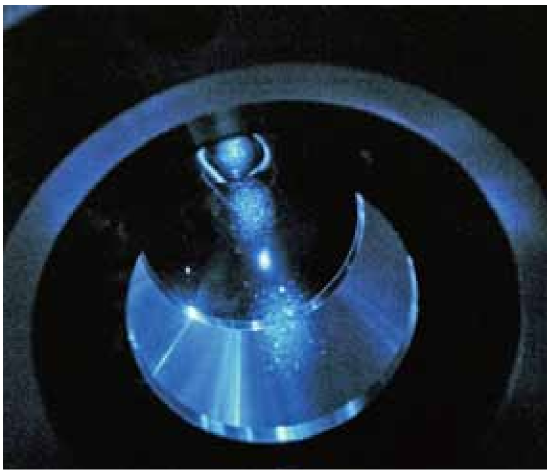


Figure 1 Sr optical lattice clock

By trapping tens of thousands of Sr atoms at the center of a vacuum tube, we can obtain atomic resonant frequencies with signal strength much stronger than that of trapped single ions.

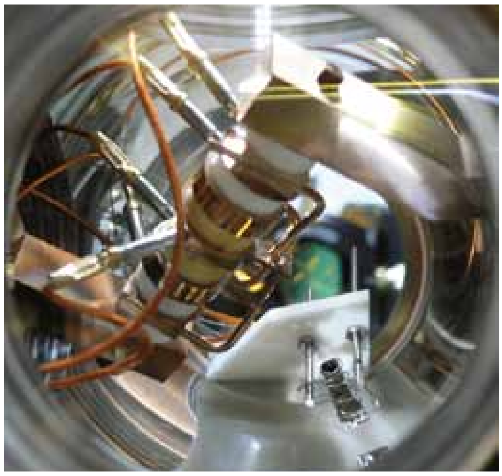


Figure 2 Ca^+ single ion optical clock

We trap just one ion in the center of a 2 mm circle emptied onto a metal plate, adjust optical frequency so that the ion is exposed to the laser beam and constantly resonates, and then obtain the standard frequency.

*1 Time information is listed in time calibration signals by time-shifting large and small amplitude, which is used in radio clocks. However, although 40 kHz and 60 kHz carrier waves in the long waveband are transmitted as the frequency standard with 12-digit precision and slightly weaken in precision during propagation, they can be received with 11-digit precision.

Sr optical lattice clock

As a result of calibrating absolute frequency based on the second generated by Japan Standard Time, NICT's Sr optical lattice clock shows good agreement of the frequency with other Sr optical lattice clocks in Japan, USA, France, and Germany as shown in Figure 3. Moreover, after transmitting an optical signal generated at NICT Headquarters (Koganei City, Tokyo) to Hongo Campus, The University of Tokyo with 60 km of optical fiber and we compared the frequency with an optical lattice clock at The University of Tokyo which is 56 m lower in altitude, relatively. Frequency difference of 2.6 Hz due to the effect of the general relativity was clearly detected, and when this difference was corrected, it was confirmed that the frequencies agreed with an uncertainty of 7×10^{-16} *2. Based on these results, the Sr optical lattice clock is now the world's first and only optical clock to have a frequency agreement of 16-digits confirmed among research institutes. In addition to the 5 research institutes in Figure 3, development is also underway at the National Institute of Advanced Industrial Science and Technology (Japan) as well as in England and China. In the future, it is expected that the Sr optical lattice clock will be the atomic clock that redefines the second. At NICT, we successfully calibrated the ratio of Ca^+ single ion optical clock frequency to this Sr optical lattice clock frequency as

$$\frac{\nu_{Ca}}{\nu_{Sr}} = 0.957\ 631\ 202\ 358\ 049\ 9$$

with an uncertainty of 2.3×10^{-15}. This equates to not just having conducted a high-precision calibration but having effectively calibrated frequency of a Ca^+ single ion optical clock based on a Sr optical lattice clock. Currently, where the second is defined by cesium atomic clocks, a frequency measurement is to measure a frequency ration against cesium atomic hyperfine transition frequency. By multiplying the calibrated ratio to the defined cesium atomic clock frequency 9,192,631,770 Hz, we take this as the frequency. In other words, "evaluating the ratio with a standard frequency" is the essence of frequency measurement, and we have for the first time measured a ratio of optical clock based on a Sr optical lattice clock and confirmed that the result is consistent with results obtained from prolonged calibrations via the conventional cesium standard. In regards to calibration time, in contrast to over 3 hours of signal accumulation required for 15-digit calibration using the conventional microwave standard, we completed the calibration with no more than 20 minutes of accumulation based on the optical frequency standard.

Meeting of Comité Consultatif du Temps et des Fréquences

The above-mentioned (1) absolute frequency calibration of a Sr optical lattice clock, (2) absolute frequency calibration of a Ca^+ single ion optical clock, and (3) frequency ratio measurement were published in international academic journals, and on this basis, NICT submitted the calibration results to a meeting of the Comité Consultatif du Temps et des Fréquences, Comité International des Poids et Mesures [Consultative Committee for Time and Frequency (CCTF), International Committee for Weights and Measures (CIPM)], held in September 2012. The results of this paper were endorsed at the Committee, and NICT calibration values are contributing to the decision of the Committee-recommended clock transition frequencies of Sr and Ca^+. Among the "secondary representations of the second" candidates for redefinition of the second whose future implementation are being reviewed, the Sr optical lattice clock realizes the smallest uncertainty (1×10^{-15}).

Furthermore, after the meeting of CCTF in September 2012 where the development results of optical frequency standards are reported, the committee urged researchers to report on frequency ratios for other optical frequency standards in addition to conventional absolute frequency (frequency ratio against cesium standard). We are proud that NICT had submitted the report ahead of this move.

Prospects

Our results demonstrated that Sr optical lattice clocks function as an optical frequency calibration standard. Our next goal in the future is to realize 17-digit accuracy by placing Sr atoms in a below −170 °C low-temperature environment such as eliminating frequency shifts from atoms sensing the slight black body radiation emitted from a room temperature vacuum chamber. It is known that Earth's gravity slightly shifts due to gravitational pulling from the moon and sun and that this causes tidal movement. According to a prediction of general relativistic theory, this slight is in the 17th digit. Perhaps in the near future, we will see optical clocks capture this effect.

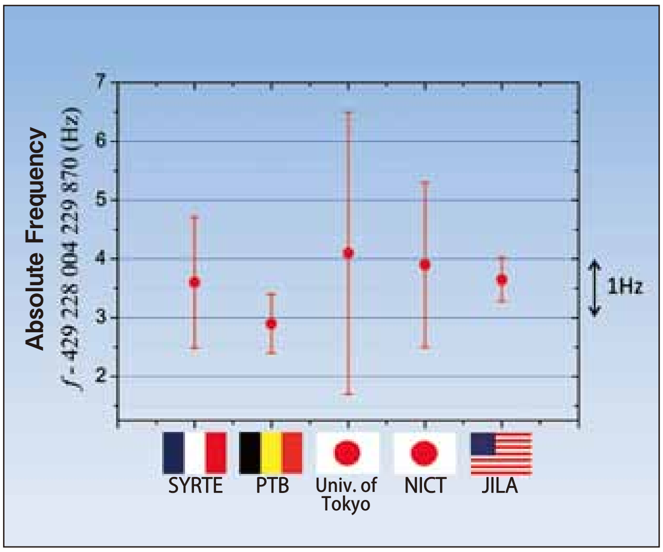


Figure 3 Frequencies of Sr lattice clocks operating at 5 institutes in 4 countries

The frequencies obtained at each research institute, approximately 429THz (429×10^{12} Hz), are consistent within a range of merely ±1Hz.

*2 For details, see NICT NEWS October 2011 issue.

Aiming for People-Friendly Information-Communications that Start from the "Brain"

—Research Outline of Center for Information and Neural Networks (CiNet)—

KASHIOKA Hideki

Managing Director, Center for Information and Neural Networks

KASHIOKA completed a doctoral program in 1993. He entered ATR the same year and later joined NICT in 2006. After serving as the Planning Manager of the General Planning Department and Director of the Spoken Language Communication Laboratory, he became the Director of the Brain Networks and Communication Laboratory in 2013. KASHIOKA is primarily engaged in natural language processing and spoken language processing research. He aims for the integration of brain science and spoken language processing. Ph.D. (Engineering).

Establishment of CiNet

Under an agreement on a large-scale collaboration for the study of brain function and applying these results to new ICT and networks (concluded January 7, 2009), on March 6, 2013, NICT and Osaka University held the opening ceremony for the Center for Information and Neural Networks (CiNet) at Osaka University, Suita Campus (Suita City, Osaka). At CiNet, we will conduct NICT, Osaka University, and ATR research and development in brain information and communication fields, from the fundamentals to application development, aiming to realize "a new generation network learned from brain functions," "earth and people-friendly technology," and innovative information-communications technology.

At the opening ceremony, in addition to OGASAWARA Michiaki, Administrative Vice-Minister, Ministry of Internal Affairs and Communications, and MORIMOTO Koichi, Deputy Director-General, Research Promotion Bureau, Minister of Education, Culture, Sports, Science and Technology, a total of 79 guests from universities, research institutes, and industry also participated. Following greetings from the hosts, MIYAHARA Hideo, former President of NICT, and HIRANO Toshio, the President of Osaka University, OGASAWARA, Administrative Vice-Minister, Ministry of Internal Affairs and Communications, and MORIMOTO, Deputy Director-General, Research Promotion Bureau, Minister of Education, Culture, Sports, Science and Technology, offered congratulatory messages on their hopes that CiNet research will contribute greatly to Japan's development. Afterwards, YANAGIDA Toshio, Director General of Center for Information and Neural Networks, explained the overview and research policies of CiNet. And finally, after a ribbon-cutting ceremony with much fanfare, CiNet officially opened (Figure 1).

Figure 1 Ribbon-cutting ceremony

(From left: YANAGIDA, Director General of Research Center, MORIMOTO, Deputy Director-General, Research Promotion Bureau Minister of Education, Culture, Sports, Science and Technology, HIRANO, President of Osaka University, MIYAHARA, former President of NICT, OGASAWARA, Vice-Minister, Ministry of Internal Affairs and Communications, and HIRATA, President of ATR)

CiNet research projects

At CiNet, we segmented our research into four interdisciplinary areas where each field will promote research towards its goals. These interdisciplinary areas aim to realize new information-communications by becoming involved with others and further increasing development integration.

●HHS (Heart to Heart Science)

The brain operates as the center of communication as both a recipient and sender of information and subconsciously processes vast amounts of information. In regards to how the brain processes a variety of visual and auditory information, we aim to realize information-communications that focus on quality rather than quantity by objectively and quantitatively capturing the states of the brain and also will conduct research and development on technology that supports the understanding of information and verbal comprehension.

●BFI (Brain-Function installed Information) Network Technology

By emulating the network functions of the brain controlled in various environments of an exceedingly complex organizational body, we can respond to the explosively increasing traffic needs, which will enable a next-generation network of extremely low-energy consumption with scalability, tenacity, autonomy, environment adaptability, and self-restoration.

●BMI (Brain-Machine Interface) Technology

We will conduct development of interface technology that interprets information one wants to convey from activity of the brain, an information receiver, and also interface technology that efficiently transmits the information the sender wants to convey.

This will lead to our development of new rehabilitation technology that uses brain information for disabilities due to a decline in brain functions from aging, etc. such as motion, speech, cognition, and sensory functions, in which we will aim for major improvements in quality of life.

●Instrumental Technologies

By developing and integrating a number of non-invasive techniques to measure brain function, we seek to design new techniques that can help us apply brain processing strategies to information and communications system.

Along with the improvement of space-time resolution in regards

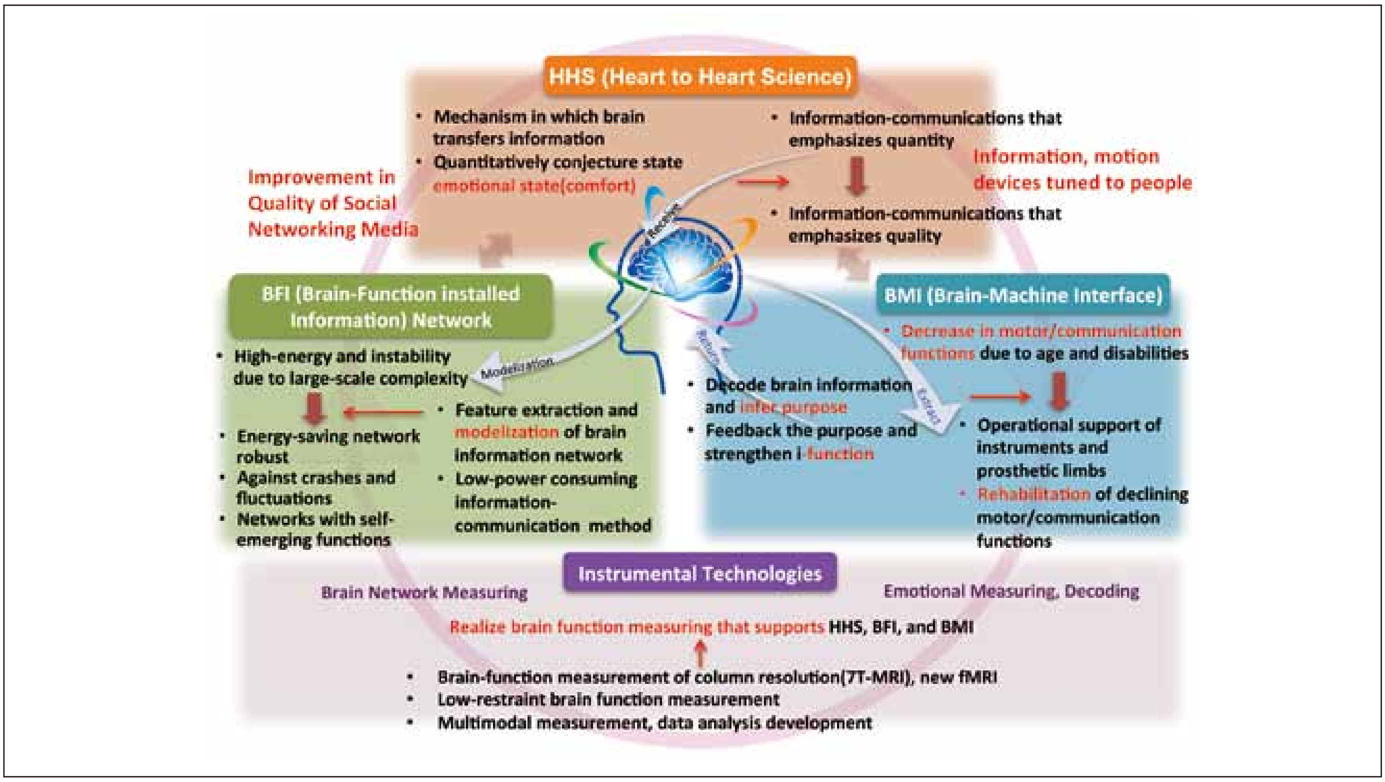


Figure 2　Four interdisciplinary areas of CiNet

to high functionality and precision, many expect the realization of practical measurement technologies such as real-time measurement and Single-Trial measurement (measurement based on one-time measurement trial). First, after analyzing brain activity via 3 Tesla Magnetic Resonance Imaging (3T-MRI) and selecting a region of interesting activity, we will use the 7T-MRI introduced in this study and aim for the realization of meticulous analysis of the column referred to as the smallest unit of brain functions.

CiNet facilities

At CiNet, we will create one of the world's most advanced research environments where, in addition to the third 7T-MRI in Japan, we will also operate cutting-edge measurement instruments such as the state-of-the-art 3T-MRI and a brain magnetic-field measurement instrument with a vast number of channels (MEG). Specifically, Suita Campus of Osaka University houses the 7T-MRI, 3T-MRI, and MEG, and Iwaoka-cho, Kobe Nishi-ku, home of the Advanced ICT Research Institute, will have brain measurement instruments including the 3T-MRI, 1.5T-MRI, and MEG, for a total of six instruments. With MRIs, we can detect changes in the hemodynamics of cells associated with nerve activity. 7T (Tesla), an MRI that uses super-high magnetic fields, has extremely high spatial resolution, and in addition to detecting nerve activity, it can also measure concentration changes of substances associated with nerve activity in the brain, in which it will increase our understanding of the brain. With MEG, by attaching multiple highly-sensitive magnetic sensors that make up the Superconducting QUantum Interference Device: SQUID around the head and measuring faint magnetic fields generated by nerve activity, it can measure brain activity in high temporal resolution (units of ms).

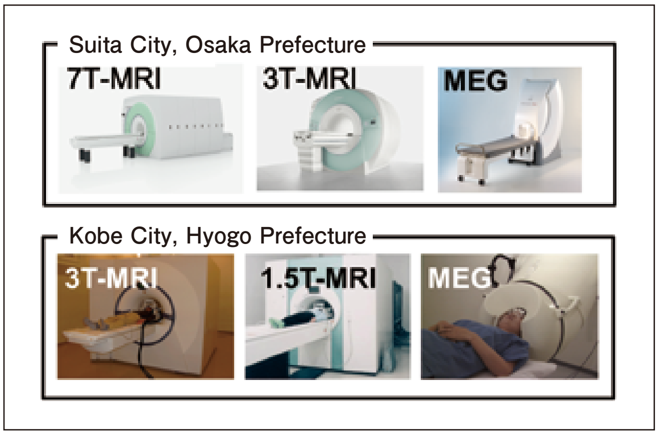


Figure 3　CiNet measurement instruments

Future prospects

At CiNet, we aim to integrate brain science and information-communications technology and realize people & earth-friendly communication technology as we promote its research and development. Up until now, we have promoted development of technology that rehabilitates impaired motion and communication functions by developing electroencephalographs suitable for practical usage as well as by extracting and using brain information. With the opening of this research center, in addition to our aim for research of new measurement methods that uses prepared state-of-the-art measurement instruments and better understanding of brain information processing and control mechanisms, we will conduct research and development while envisioning a system architecture for real-world application. We will work on technologies that transmit information to devices as well as processing information used in the brain structure—by miniaturizing/enhancing performance of measurement devices and speeding up processing—and aim for innovation in creating information-communications technologies. Furthermore, we will make great efforts on not only research field integration but also personnel development and international researcher exchanges and aim to realize communication technology that will become core next-generation technology.

The Efficiency of Functional Brain Network Deteriorates with Sleepiness

MIYAUCHI Satoru

Chief Senior Researcher, Planning Office, Advanced ICT Research Institute

After completing a doctoral course, MIYAUCHI studied at Brown University (USA) and worked at the National Institute for Physiological Sciences, National Institutes of Natural Sciences. In 1993, he joined Communications Research Laboratory (currently, NICT). He is mainly engaged in research and development related to non-invasive brain function measurements of fMRI, Magnetoencephalography, and brain waves. Ph. D. (Medicine).

Information processing of the brain is a game of whisper down the lane

Think of a situation where you are passing a message through one person to another, like a game of whisper down the lane (Figure 1a). As the number of people mediating the message increase, conveying information takes longer. The possibility increases that the message could change midway (Figure 1b) and fail to be conveyed to the end (Figure 1c). This is common in inefficient organizations, and our brains are no different. Our brain processes a variety of information from the external world (e.g. visual, auditory, tactile information and so on) in an area that processes each modality of sensory information. It is sent to the more integrated processing area (association cortex), and then to the frontal lobe where the information is integrated with memory and the physical condition to make the best decision depending on the actual situation. Finally, the brain outputs the decision to the motor cortex for the actual action.

Is reduced efficiency when you are drowsy a matter of course?

Surely many have had frightful experiences behind the wheel as they fought off drowsiness. When we become drowsy, we often neglect important stimuli, and even when noticing these stimuli, our reactions become slower. Why is this? We have known for decades how our brain activity changes when we are drowsy compared to when we are awake. For example, when we are dozing off, slower brain waves appear than when we are awake (Figure 2a). Still, we could not neurophysiologically explain why this kind of change in brain activity appears as a change in behavior such as neglecting stimuli and slower reactions.

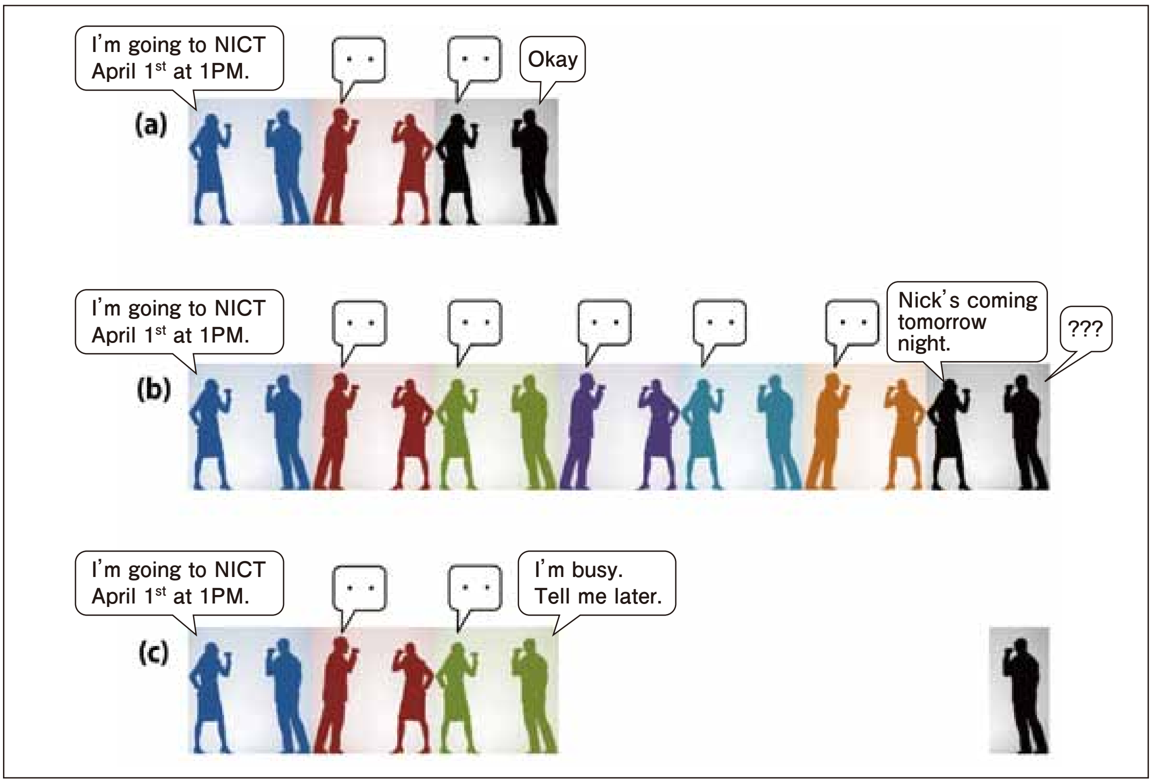


Figure 1 Information processing of the brain is akin to a game of whisper down the lane

Simultaneous measuring system of functional Magnetic Resonance Imaging(fMRI) & brain waves

There is a difficult problem when attempting to check brain activity with functional Magnetic Resonance Imaging (fMRI) while the subject is drowsy or sleeping. fMRI clearly reveals the active areas of the brain in high-spatial resolution but does not know whether the subject inside of the device is awake, drowsy, or sleeping. Conversely, with brain waves, we cannot know exactly which part of the brain is active, but waveforms do change sharply according to the subject's drowsiness (Figure 2a). We can take an ideal measurement if we measure the fMRI and brain waves together. However, because a strong magnetic field exists inside the fMRI machine, it has been difficult to measure weak brain waves. At the Advanced ICT Research Institute, we have constructed a system that can measure and analyze brain waves, fMRI and infrared camera video images with temporally synchronized fashion (Figure 2b). Using the system, we have so far revealed that the primary visual cortex is activated accompanying eye movements during dreaming.

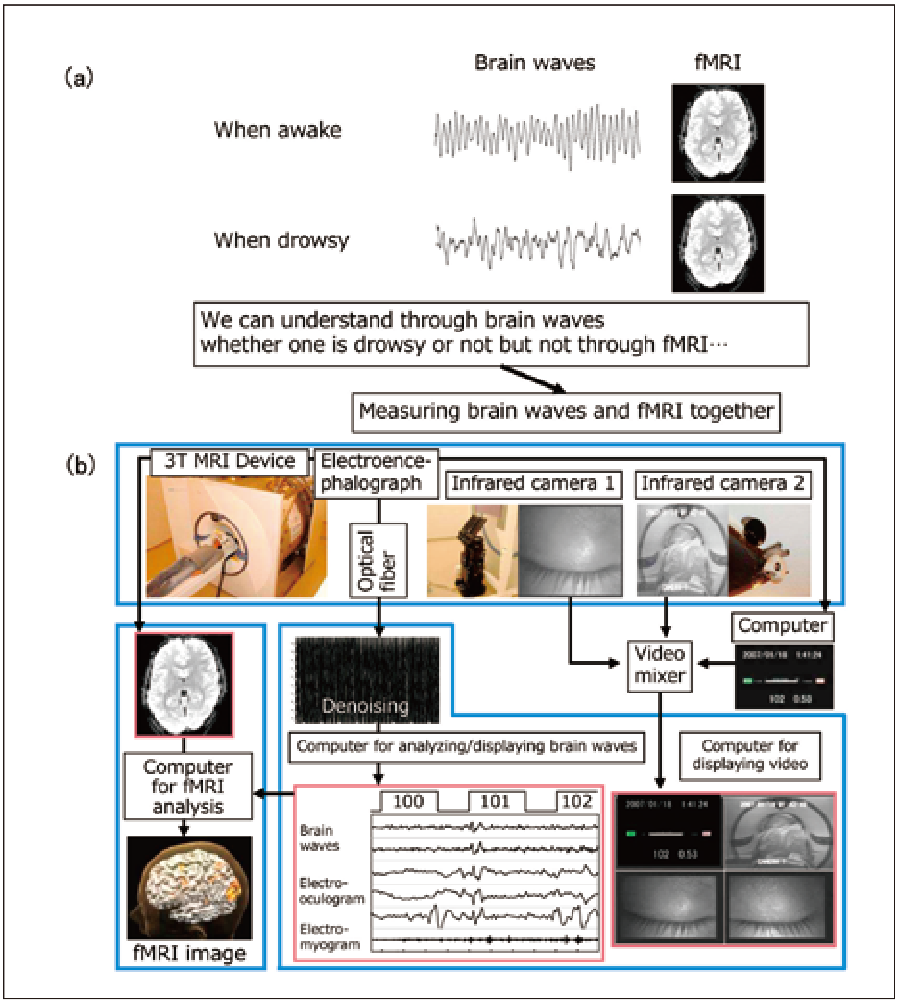


Figure 2 Brain wave-fMRI-video simultaneous measurement/analysis system developed at the Advanced ICT Research Institute

Brain information processing and Complex Network Analysis

In collaboration with the School of Medicine, Kyushu University and using this system, we measured brain activity during times of waking and drowsiness with fMRI, and using a method called Complex Network Analysis*, examined how the information processing network of the brain changes.

As a result, during drowsy state, for example when information is transmitted from area 1 to 2 in Figure 3, like Figure 1b of the game of whisper down the lane example mentioned in the beginning, we found that information fails to be transmitted when not passed through more areas. During drowsy state, the information processing system of the brain was inefficient. We also found that the inefficiency was not the whole brain but the network composed of multiple areas that are active and coordinate with one another when we are inactive and at complete rest known as the Default Mode Network (DMN). In brain research using conventional fMRI, we have identified the brain areas associated with specific information processing by stimulating subjects, giving them tasks, and calculating the difference with a resting state without stimuli or tasks. However, we found that even in an inactive state of rest, the brain is active and consumes an enormous amount of energy, and as a result of our analysis of resting-state brain activity in the absence of stimuli and tasks, it was revealed that there are several types of networks in our brains where multiple brain areas are coordinating and at work, even in a resting state. Among them is the specifically active network in a resting state called the Default Mode Network. It has been known that this network's activity deteriorates in various neuropsychiatric and consciousness disorders such as dementia. In the future, we will analyze DMN during deep sleep (slow wave sleep), sleep while dreaming (rapid eye movement sleep), and elucidate their relationships with consciousness and neuropsychiatric disorders from the standpoint of an information-processing network.

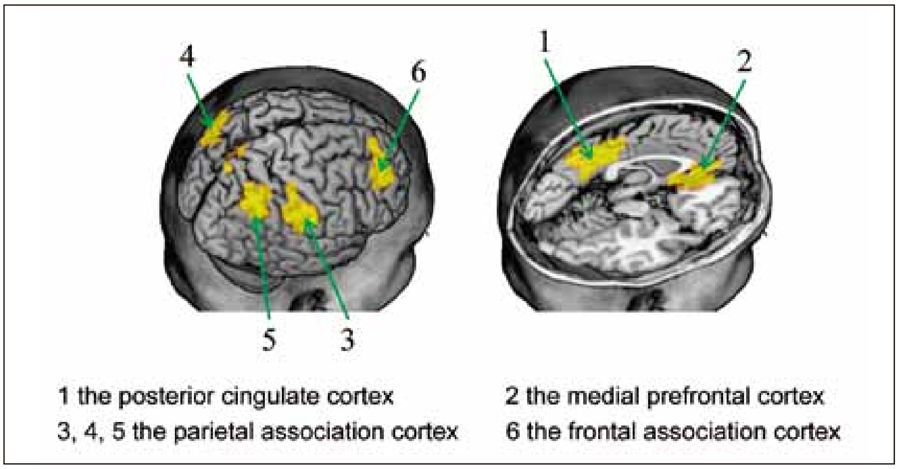


Figure 3 Areas of brain with reduced efficiency when drowsy

* Complex Network Analysis
Mathematical technique developed from graph theory pioneered by the mathematician, Leonhard Euler, who solved the so-called one-stroke sketch problem that asked, "Could you cross all seven bridges over a river, only once each bridge, and return to the original starting point?" (The Seven Bridges of Königsberg). With the increasing performance of computers, we can now quantitatively analyse staggering amounts of data from complicated and real-world networks and phenomena. As familiar examples, this applies to analysis of Internet links, route maps of airplanes/railways, and power grids, among others.

Routine Ionospheric Observation at Showa Station, Antarctica

—For space weather monitoring and understanding long-term variations—

NAGATSUMA Tsutomu

Research Manager, Space Weather and Environment Informatics Laboratory, Applied Electromagnetic Research Institute

After completing a doctoral course, NAGATSUMA joined Communications Research Laboratory, Ministry of Posts and Telecommunications (currently, NICT) in 1995. He is engaged in research and development in Space Weather Forecast. Ph.D. (Science).

What is the ionosphere?

At an altitude of about 60 km and above lies a region of the upper atmosphere called the "ionosphere (ionization layer)" . The ionosphere is formed primarily by the action of solar Extreme Ultra-Violet (EUV) and X-ray radiation on the atomospheric particles. The sunlight strips electrons from neutral atoms and molecules and produces a partially ionized gas (plasma). High-Frequency (HF) radio waves have been used in long-distance radio communications because of its property of bouncing off the ionosphere. In contrast, Ultra High Frequency (UHF) and microwave frequency radio waves are employed for applications such as Earth-satellite communications and satellite positioning since they can path through the ionosphere. It is known that the state of the ionosphere changes depending on the solar activity and the Earth's space environment. The lower atmosphere also affects the ionosphere. Such changes in the space environment sometimes cause the ionospheric storms to occur due to which radio communication gets disturbed. Small changes in the ionosphere can simply disturb the radio waves — a phenomenon known as scintillation. In the polar regions, the scintillation occurs due to ionospheric disturbances associated with aurora activity, whereas in the equatorial regions it occurs in places where ionospheric low-density cavities called "plasma bubbles" are formed. When this scintillation is extremely strong, it can black out satellite communications completely. Also, free electrons in the ionosphere slow down the propagation of radio waves during their passage through the ionosphere. The velocity of the radio waves varies in correlation with the number of electrons (Total Electron Content or "TEC") in the layer through which radio waves pass through. Thus, ionospheric disturbance even causes errors of satellite positioning and navigation.

At NICT, we have been researching, developing and operating space weather forecasting to monitor not only ionospheric disturbances but also disturbances in space environment associated with solar activity in order to improve the safety and security of communications, broadcasting and satellite positioning systems. We have continuously monitored the ionosphere in Japan for over 60 years. Currently, we vertically monitor the ionosphere every 15 minutes in 4 locations—Hokkaido (Sarobetsu), Tokyo (Kokubunji), Kagoshima (Yamakawa), Okinawa (Ogimi)—and provide the observation and information on our Website (http://wdc.nict.go.jp/IONO/) (Japanese). Aside from the Japan islands, we are also conducting ionospheric observation at Showa Station in Antarctica. This article outlines the history of our continuous routine observation of the ionosphere and also provides the detailed information on observations currently being conducted, as one of NICT's routine observatory activities at the Showa Station in Antarctica.

History of ionospheric observation at Showa Station

Japan's Antarctic observation project started as part of the activities implemented during the International Geophysical Year (IGY) 1957/58. From the early stage of this national observation project, the Radio Research Laboratory (RRL, the former name of current NICT) has continuously dispatched team members to Antarctica as part of this project and had conducted ionospheric observations (Figure 1). The first team installed an ionosonde and antenna on board the Antarctic observation ship, Soya, and conducted ionospheric observations in Antarctica and along the ship's course. Routine observation at the Showa Station began with the third team (1959) and has since been continuing with every team member dispatched to Antarctica. Throughout this period, we conducted many other observation by the way of aurora radar, Riometer[*1], HF field strength measurement, and measurement of VLF waves, and achieved significant results including the identification of two-dimensional distribution characteristics of precipitating auroral particles and solar cycle dependence of the occurrence frequency of radio aurora.

Figure 1 Radio Research Laboratory party that participated in the first Antarctic expedition team
(from "25 years of Antarctic Radio Wave Observation")

*1 Riometer (Relative Ionospheric Opacity Meter)
An instrument to quantify the fluctuations of radio noise strength or degree of absorption caused by the distribution of aurora particles that increase the density of electrons in the ionosphere. This is done by measuring the strength of the cosmic radio noise in tens of MHz of bandwidth.

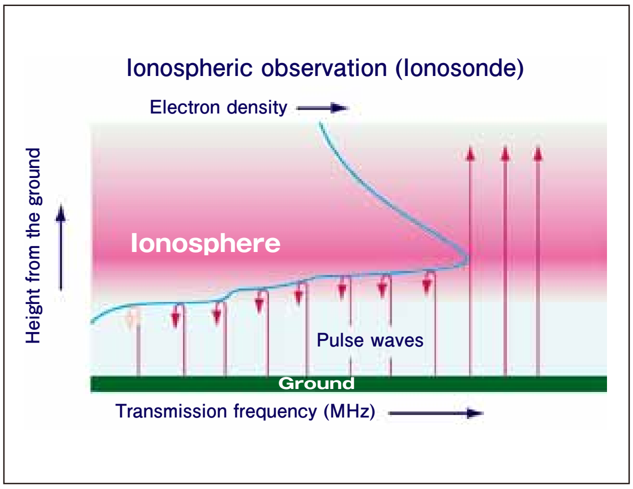


Figure 2 A schematic picture showing measurement principle of bottom-side sounding (ionosonde)

Figure 3 Ionosphere observation delta antenna and aurora at Antarctic Showa Station

Current observations

Currently, NICT is conducting three types of observations in Antarctica and along the course of the ship, Shirase, from Japan to Antarctica and back. More detailed information follows below.

—Vertical observation of the ionosphere (ionosonde)

Bottom-side sounding is a method that applies the principles of radar to observe vertically-oriented (height) electron-density profiles of the ionosphere. It measures the time it takes for HF-band radio waves launched vertically from the ground to be reflected off of the ionosphere and return, and then estimates the height of the ionosphere that reflects radio waves of a certain frequency. Because the frequency of ionospherically-reflected radio waves is a function of electron density, it is possible to estimate the variation in height-profile of ionospheric electron density by measuring the time for radio wave reflection with respect to each frequency (Figure 2). The instrument used in this observation is known as an ionosonde. We have used pulse-type ionosonde for a long time at NICT but are currently working on a transition in method of observation as we develop an instrument of a new system called FMCW*2 that realizes power-saving and labor-saving of maintenance work (Figure 3).

—GPS scintillation observation

In the Arctic and Antarctic polar ionosphere, electron density fluctuates with the electrons and ions precipitation from the magnetosphere, which is the primary cause of aurora. Due to this density fluctuation, scintillation takes place on the satellite communication radio waves. As the plasma flow causes horizontal advection of small-scale density fluctuations, scintillation patterns show time lags depending on the place of observation. At NICT, we installed 3 instruments to observe GPS scintillation signal at Showa Station in Antarctica and are now developing methods of estimating the horizontal drift speeds of the ionospheric plasma by comparing data from the 3 instruments, and studying the effects of scintillation on GPS radio signal reception.

—Observation of LF standard time and frequency signal

In order to better understand how LF standard time and frequency signals used for radio clocks propagate across long distances, we are observing the phase and field strength of LF standard time and frequency signals along the course of the Antarctic research expedition icebreaker, "Shirase", from Japan to Antarctica and back. This work is performed under the cooperation with the Space-Time Standards Laboratory. We compared this data to calculation results based on a new field strength prediction method developed by NICT for long distance propagation of LF waves and demonstrated that the calculation results well matches the observation data. This calculation method was recognized by the International Telecommunications Union Radiocommunication Sector (ITU-R) in 2009 as the international standard of field strength prediction methods for long distance propagation of LF waves (For details, refer to "Propagation Properties of LF Standard Frequency Waves and Development of Field Strength Prediction Method" in NICT NEWS December 2011).

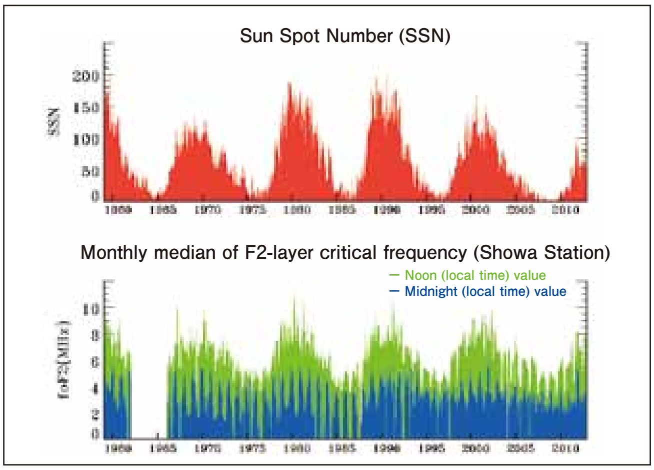


Figure 4 Long-term variations in solar activity and the ionosphere

Future Antarctic observations

With more than 50 years of Antarctic observations, NICT made significant advances in the studies on the relationship between ionospheric disturbances and solar activity and upper atmospheric fluctuations. Further, our long-term data set is beginning to reveal the ionospheric altitude variations that suggest a relationship with global warming (Figure 4). Looking ahead, we will continue observations, monitoring ionospheric disturbance in the polar regions, to provide reliable and useful solar-terrestrial information that will serve to improve the accuracy of the space weather forecasting and to reveal the characteristics and the causes of long-term variations of the Antarctic ionosphere.

*2 FMCW
Abbreviation of Frequency-Modulated Continuous-Wave.

Type Approval Test for Radio Equipment

MIYAZAWA Yoshiyuki

Expert, Electromagnetic Compatibility Laboratory, Applied Electromagnetic Research Institute

In 1978, MIYAZAWA joined the Radio Wave Research Laboratory (currently, NICT) and engaged in project management at the Planning Department. In 1984, he moved to the Test and Calibration Section, Communications System and Apparatus Divisions where he has since been consistently engaging in type approval test-related work.

What is type approval testing?

A type approval test is an examination based on international treaties such as the International Maritime Organization (IMO) and International Civil Aviation Organization (ICAO) that discerns whether radio equipment used in human life-saving and rescue systems possesses internationally-defined capabilities even in difficult environments of distress. NICT has been conducting type approval testing as a contract operation with the Ministry of Internal Affairs and Communications even after its transformation into an independent administrative institution in April 2001.

History of type approval testing

Following the "Enactment of the Type Approval Examination System" of 1935, radio equipment type approval testing began at the Radio Telegraph Research Division, Electrotechnical Laboratory, Ministry of Communications at the time (currently, NICT). Here, I will introduce type approval testing of radio equipment.

1912 was the tragic year that the British luxury liner, Titanic, collided with an iceberg, causing the loss of over 1,500 lives. As a result of the Titanic shipwreck, The International Convention for the Safety of Life at Sea (SOLAS) was enacted in 1914, revised in 1929, and put into effect in 1933. This revision made it obligatory to install onboard ships auto-alarms that receive distress signals and a radio compass that searches the direction of the distress station.

In response to the revision, the Ministry of Communications (at that time) established the Radio Compass and Auto Alarm Type Approval Examination Regulations in 1935, and radio equipment type approval began to examine and check for consistency with technology standards.

Type approval testing was initially only for safety of human life. However, two clauses were appended to the Rules for Type Approval of Radio Equipment in Radio Law that went into effect after the war: "Required Equipment for Radio Regulation" as obligatory models and "Equipment that Contribute to the Simplification of Radio Station Establishment Procedures" as discretionary models.

At the time, all equipment was being tested at the Radio Wave Research Laboratory of Posts and Telecommunications Ministry (currently, NICT). However, because discretionary testing models increased as radio wave usage advanced, the MMK: Radio Equipment Inspection and Certification Institute (currently, Telecom Engineering Center), established as the designated testing organization in 1978, implemented testing of discretionary testing models, and a scheme to certify testing results was introduced at the Radio Wave Research Laboratory. Later in 1999, the discretionary testing system was unified with the certification of conformance to technical standards, and a written application system was introduced as a diverse testing method.

Currently, testing applies to 40 types of radio equipment, but not every model is applied for every year. However, at NICT, we are working hard at operating and maintaining test equipment in order to run through the certification process smoothly when there is an application.

Open-air and shipboard testing

Type approval testing consists of an "environment test" to examine if there is any breakage or performance decline in shipping and aviation environments—their temperatures, humidity, and impacts—where the equipment is actually used, and also a "performance test" to examine whether the equipment has specified capabilities or not such as electrical power, frequencies, and protocols.

At NICT, we have 20 m drop testing equipment consisting of a pool for drop testing and a steel tower (Figure 1). Among environmental tests for equipment used at sea (JIS F0812: IEC60945), this drop testing equipment is for checking that equipment able to float at sea does not break when dropped from a ship into the sea, and if submerged to a specified depth, that it automatically floats and operates normally. After applying a drop shock, we conduct various testing using performance and temperature/humidity testing equipment.

Furthermore, in 2008, the technology standards of marine radars, which receive the most applications every year, underwent major revisions due to regulatory revisions by the International Telecommunication Union, Radiocommunication Sector (ITU-R) and implementation of recommended testing laws. Given these revisions, marine radar measurement was changed from being done under calibration laws that connect measuring devices with conventional transmitters via waveguides to actually measuring unnecessary radiant waves emitted from antenna.

Figure 1　20 m steel tower from where equipment is dropped

Figure 2　Farm road landing field at Fukushima Sky Park

Figure 3　Steel tower for testing in Niigata

Figure 4　Scene of shipboard testing

Moreover, in IEC62388, enhancement of target detection ability testing was added that surveys objects of various conditions (cliffs, small islands, sea route buoys, etc.).

As a result, spurious measurement, the examination method recommended by ITU-R, now required space to conduct far-field distance measurement (200–500 m) in order to reduce measurement errors. As such a place could not be secured on NICT property, we surveyed all around the country for places that matched the conditions but could not secure a constant measuring place. Therefore, we considered the temporary use of a small-scale aircraft landing field and decided to use Fukushima Sky Park, a farm road landing field (Figure 2). However, because there was takeoff and landing priority as a condition for a temporary use, we had to suspend measurements during the takeoff and landing of aircraft and redo preparations for remeasurement all over again every time. Also, with measuring equipment damage caused by wild animals such as monkeys, each piece of equipment which normally took around three days of measurements ended up taking over two weeks. Furthermore, because of continuous runway decontamination work being done and cracks in the runway caused by the Great East Japan Earthquake, temporary use of this landing field was difficult. Currently, we are using a runway at Taiki Aerospace Research Field, Hokkaido. However, because JAXA conducts tests year round on this runway, we can only use it provisionally and hence face a major challenge in securing a constant measuring place.

Responding to international standardization and future challenges

Meanwhile, because it is necessary in target detection ability testing to confirm from land and a ship whether a target object's "detection capability is over 80%" with over 10 m/s winds and a 15 m-high antenna, in February 2010, the Ministry of Internal Affairs and Communications set up a steel tower for testing on city property of Joetsu City, Niigata Prefecture based on survey results centered around the Sea of Japan (Figure 3).

In February 2011, NICT installed a long-distance buoy to be measured and began testing. However, due to the severe natural environment, the buoy is constantly damaged, and the fact that we cannot test from land as much as we would like, we are in a continuing situation where we must do all our testing at sea from a chartered ship (Figure 4). As a result, the construction of a system that can conduct testing safely from land is promptly needed.

At NICT, because we do not only implement type approval testing but also contribute to equipment subject to future type approval testing and the improvement of measuring precision, we are conducting technology standard development and international standardization activities. Specifically in unnecessary radiation measurement of radar, we actively participate in ITU-R meetings, conduct collaborative testing with the American measuring group, National Telecommunications and Information Agency (NTIA), writing contributive papers. And we also actively participate in international standardization activities for radio equipment testing.

In type approval testing, as it becomes necessary to confirm the functions of equipment improving everyday, continuous research and develop of equipment and testing methods for confirming will be demanded. Other major challenges include the succession of various kinds of know-how for confirmation and personnel securement.

At NICT, we hope to continue contributing to the realization of the prosperous, secure, and safe livelihood of the people through type approval testing work that plays an important role in the safety of people's lives, protection of assets, and maintaining radio wave usage order.

●**Type approval test staffs**
(from left: KAWAHARA Masatoshi, SHIOTA Sadaaki, ANEGAWA Kumiko, MIYAZAWA Yoshiyuki)

Calibration of Measuring Instruments and Antennas for Radio Equipment


From left: FUJII Katsumi, NISHIYAMA Iwao, SEBATA Kouichi, SUGIYAMA Tsutomu

FUJII Katsumi

Research Manager, Electromagnetic Compatibility Laboratory, Applied Electromagnetic Research Institute

After completing a doctoral program and serving as a Research Associate at the Research Institute of Electrical Communication, Tohoku University, FUJII joined NICT in 2006. He is engaged in research related to calibration of measuring instruments and antennas for radio equipment and EMC measurement. Ph.D. (Engineering).

What is calibration?

Calibration measures and examines how much a value displayed by a measuring instrument corresponds to the correct standard value and the difference from the correct value, and then makes adjustments so that the measuring instrument displays the correct value. In Japan, although radio waves are used based on the "Radio Law" established in 1950 for fair and efficient use of radio waves, quality—the frequency and strength—of all radio waves emitted from radio equipment, from mobile phones and transceivers to the television broadcast transmitter installed at the TOKYO SKYTREE and transmitters equipped to artificial satellites, is examined by calibrated measuring instruments and supervised so that they do not interfere with or block other radio stations.

History of calibration

According to the Radio Law, the Technology Division, Radio Department, Radio Regulatory Agency was in charge of calibration of measuring instruments used by radio station inspections conducted by the Radio Regulatory Committee (currently, the Ministry of Internal Affairs and Communications). However, once the Radio Wave Research Laboratory (currently, NICT) was established in August 1952, a part of the work at the Technology Division was incorporated into the Radio Wave Research Laboratory, and the Radio Wave Research Laboratory became in charge of calibration operations. Because calibration for all types of measuring instruments used in radio equipment testing is done by comparing standard instruments that the Radio Wave Research Laboratory maintains and manages, measuring with calibrated measuring instruments is, in an indirect sense, equivalent to measuring with Radio Wave Research Laboratory standard instruments. Initially, calibration conducted by the Radio Wave Research Laboratory targeted only sub-standard instruments maintained and managed by the Regional Radio Regulatory Bureau, Ministry of Posts and Telecommunications (currently, Regional Bureau of Telecommunications, Ministry of Public Management, Home Affairs, Posts and Telecommunications). However, in 1959, they began to accept calibration of measuring instruments from places other than the Regional Bureau of Telecommunications (commissioned calibration system). Later, in 1999, many big legal revisions were made such as the introduction of the Technical Regulations Conformity Certification system and creation of the designated calibration organization system in 1999, and designated calibration organizations starting to conduct sub-standard instrument calibration of the Regional Bureaus of Telecommunications (Regional Radio Regulatory Bureau reorganized in 1985). Meanwhile, although the Radio Wave Research Laboratory(1952 –) changed to the Communications Research Laboratory(1988 –) and then to NICT(2001 –), calibration work continued unfazed over a span of 60 years. Currently, as a general rule, based on a decision of the Government Revitalization Unit, only designated calibration organization instruments for calibration are subject to calibration.

Calibration coverage

With the exception of frequency standard instruments, the Electromagnetic Compatibility Laboratory, Applied Electromagnetic Research Institute of NICT is currently in charge of calibration work of all radio measuring instruments. Calibration targets include fundamental measuring instruments critical for using radio and types of antenna, or more specifically, ranges in frequency counters, RF power meters, RF attenuators, signal generators, spectrum analyzers, voltammeters, field strength meters, antennas, and SAR (Specific Absorption Rate) measuring probes. Furthermore, the target frequency of measuring spans all frequencies, from DC(0 Hz) and utility frequency(50/60/400 Hz), to LF, MF, HF, VHF/UHF, microwave, millimeter wave, and terahertz wave(up to 3 THz). If you add the differences in measuring instruments by manufacturers and differences in antenna forms, there are dozens measuring instrument types covered. Open-area test sites, anechoic chambers, and shield rooms are all necessities for radio measurement, and characterization associated with each frequency band of these facilities is being studied. Each and every instrument requires in-depth specialized knowledge, calibration technology, and measuring technology, and the one-of-a-kind knowledge and experience at NICT not found in other areas of work or research-development is in high demand.

Diversified radio usage and calibration technology

The number of radio stations at a mere 5,610 in 1950 has since surpassed 140,000,000 stations and is expected to continue increasing in the future.

For example, currently there is research and development being conducted on radio transmissions that use millimeter waves—120 GHz and 300 GHz—in order to enable large capacity/high speed transmissions such as high-definition television. On the other hand, in the low-frequency bands, there is concern that unnecessary electromagnetic noise emitted from switching power supply widely used by energy-saving products and home appliances, called "green products", cause deterioration of the electromagnetic environment by obstructing other radios. Calibrating measuring instruments to accurately measure radio waves is becoming increasingly important in order to safely and comfortably use radio. At NICT, through calibration work, we are providing technology that supports social infrastructure and responds to the radio usage needs of society.

Two ways to write "calibration": The Japanese word "Kousei", for measuring instruments, can be written in two different forms as「較正」(calibration) and「校正」(calibration). Legally,「較正」is based on the Radio Law and「校正」is based on the Measurement Act.「較正」includes the adjustment of measuring instruments but「校正」does not.「校正」is designated as showing on a certificate the difference between values displayed by measuring instruments under calibration and correct values (standard instruments), and so the meaning in which it is used is opposite of the actual meaning of its Chinese characters,「較」・「校」. In general, the「校正」characters are widely used. Currently at NICT, we use both「較正」and「校正」, but because the manufacture' s warranty becomes void once we open a measuring instruments case, we currently do not adjust measuring instruments even if it is「較正」, and the content of the application of both types of calibration is the same.

Sightseeing Spots Recommender System "Kyo no Osusume"

SUGIURA Komei

Researcher, Information Services Platform Laboratory, Universal Communication Research Institute

He received his Ph.D. degree in informatics in 2007. He was a research fellow of JSPS, and joined NICT in 2008. His research interests include robot dialogue, spoken dialogue systems, and machine learning.

Introduction

Many tourists collect tourist information orally or from guidebooks and websites, etc. Based on this information, they decide on places such as Kyoto, Paris or Rome, where they would visit when they go sightseeing. However, there are too many sightseeing spots in these cities; thus, it takes a lot of time to find out preferred spots.

Based on these backgrounds, we constructed the spoken dialogue system "HANNA" that assists in forming sightseeing plans and "Kyo no Osusume", a recommendation system that turns the HANNA sightseeing spot recommendation function into a smartphone application. With "Kyo no Osusume", the user can get sightseeing spot recommendations easily through a touch panel interface by selecting items such as mood (for healing, for refreshment, etc.), experience, atmosphere, and sightseeing spot character. It is difficult to search based on subjective criteria such as feeling, etc. with conventional searching, but in this system, we enabled recommendations that incorporate both objective and subjective criteria.

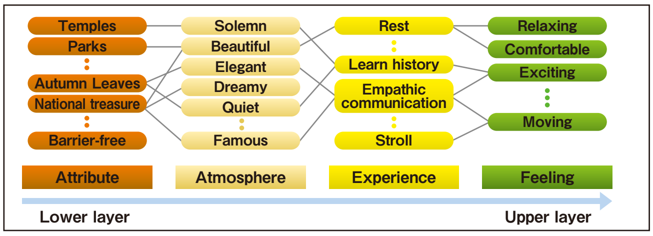


Figure 1 Evaluation structure for Kyoto sightseeing spots

Constructing an evaluation structure based on Evaluation Grid Method*

In order to find out what kind of evaluation criteria that sightseeing spots are selected upon, we interviewed 24 subjects based on Evaluation Grid Method and conducted free comment questionnaires with 1,000 subjects, and from those extracted 137 evaluation criteria (items) such as "world heritage" and "not famous". Next, we conducted questionnaires with 4,000 subjects and decided the significance of links with the evaluation structure topology based on statistical significance (Figure 1). This evaluation structure quantifies the hierarchical relationship between specific features (park, etc.) and abstract values ("you can relax," etc.).

Recommendation of sightseeing spots

Initial system screen is shown in left picture of Figure 2. First, users select one category from four of "mood", "experience", "atmosphere", and "spot character". Next, they select evaluation criteria (item) such as shown in the middle picture of Figure 2. Each sightseeing spot score is calculated by finding the product of conditional probability to each selected evaluation criteria assuming the value of a certain item does not affect the value of the other items, and then displayed on the bottom of the screen. At the moment, basic information, history, and videos are available on 150 sightseeing spots.

For more information, visit http://mastar.jp/kyonoosusume/index.html (Japanese).

Figure 2 "Kyo no Osusume" screenshots
(left: startup screen middle: category-selection screen right: basic information on spots screen)

Conclusion

Today, in an age of information overload, users demand useful information amongst the vast amount of information in networks. Besides our "Kyo no Osusume" app reaching over 20,000 downloads, the recommendation algorithm we developed was introduced on February 28, 2013 to the sightseeing portal site operated by the Industry and Tourism Bureau, City of Kyoto, "Kyoto Sightseeing Navi." There, a wide range of users is utilizing our research results. We hope to continue promoting recommender systems in the future to both utilize and apply information to a wide variety of data.

* Evaluation Grid Method
An in-depth psychological interview method that extracts, as a hierarchical structure of causal relations ranging from objective facts to inner values, individual needs and preferences. It is used in areas of architecture and marketing product development.

Awards

Recipient(s) ● **UTIYAMA Masao** / Senior Researcher, Multilingual Translation Laboratory, Universal Communication Research Institute

Co-recipients:
Over 60 persons listed on
http://trans-aid.jp/ANPI_NLP/

◎Award Date: June 14, 2012

◎Name of Award:
Field Innovation Award 2011

◎Details:
In recognition for significant contributions to practical challenges of society in AI technology research and its business solutions

◎Awarding Organization:
The Japanese Society for Artificial Intelligence

◎Comment from the Recipient(s):

This award was conferred to our group, ANPI_NLP, an effort to help support safety information by applying natural language processing technology (NLP) to confirm the well being of people in disaster stricken areas during the Great East Japan Earthquake. ANPI_NLP was formed by natural language processing researchers in response to a call on Twitter that aims to utilize NLP to organize Great East Japan Earthquake safety information. We are delighted that this activity was recognized.

Recipient(s) ● **KASHIOKA Hideki** / Director of Spoken Language Communication Laboratory, Universal Communication Research Institute (Currently, Managing Director, Center for Information and Neural networks)
● **KIDAWARA Yutaka** / Director General, Universal Communication Research Institute
● **HORI Chiori** / Research Manager, (Currently, Director of) Spoken Language Communication Laboratory, Universal Communication Research Institute
● **MISU Teruhisa** / Researcher, Spoken Language Communication Laboratory, Universal Communication Research Institute (Currently, Honda Research Institute USA, INC. Scientist)

◎Award Date: October 19, 2012

◎Name of Award:
DOCOMO Mobile Science Award

◎Details:
For outstanding research results based on "development of the mobile spoken dialog system (AssisTra: Kyoto sightseeing concierge)"

◎Awarding Organization:
Mobile Communication Fund

◎Comment from the Recipient(s):

We are extremely delighted to have been rewarded for our research on spoken dialog systems worked on at the Spoken Language Communication Laboratory. Although four names were mentioned in receiving this award, many in the Laboratory worked on the results. We are extremely grateful to all those in the Laboratory who supported us and everyone involved from NICT. In the future, we won' t stop here but continue our efforts on research activities that lead our field.


KASHIOKA Hideki


KIDAWARA Yutaka


HORI Chiori


MISU Teruhisa

Recipient(s) ● **SAKANO Yuichi** / Researcher, Multisensory Cognition and Computation Laboratory, Universal Communication Research Institute
● **ANDO Hiroshi** / Director of Multisensory Cognition and Computation Laboratory, Universal Communication Research Institute

◎Award Date: November 3, 2012

◎Name of Award:
The grand prize in the fourth Illusion Contest in Japan 2012

◎Details:
The illusion (Scales Illusion) and demonstration were awarded the grand prize in the fourth Illusion Contest in Japan 2012.
The illusion published on the contest webpage:
http://www.psy.ritsumei.ac.jp/~akitaoka/sakkon/sakkon-e.html

◎Awarding Organization:
Referee board of the fourth Illusion Contest in Japan

◎Comment from the Recipient(s):

This optical illusion is one in which characteristics of the spatial cognition mechanism in humans that captures horizontal and vertical directions are revealed. We received this award because our easy-to-understand expression of this type of human perception/cognitive characteristic was highly acclaimed. In the future, we hope to propose a method for enhancing presence by using the characteristics of human perception and cognition. We would like to thank all those who supported and cooperated with us.


From left: SAKANO Yuichi, ANDO Hiroshi

Recipient(s) ● **KAWANISHI Tetsuya** / Director of Lightwave Devices Laboratory, Photonic Network Research Institute

◎Award Date: January 1, 2013

◎Name of Award:
IEEE Fellow

◎Details:
For contributions to high-speed and precise lightwave modulation technologies

◎Awarding Organization:
The Institute of Electrical and Electronic Engineers (IEEE)

◎Comment from the Recipient(s):

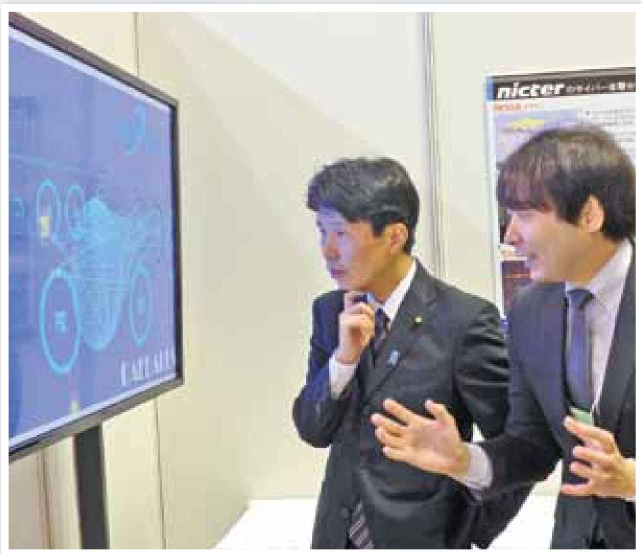
I am grateful to my seniors who had supported me. This IEEE Fellow is thanks to their advice and guidance. This award is also in recognition for the results we achieved together from collaboration with research institutions in and outside of Japan. I think this shows not only the quality of the "hard," physical side of the NICT research environment but also the "soft," intangible side such as smooth collaborative research and effective publicity. There were also many contributions from student activities, and I would like to express my gratitude to all those in the Laboratory including the trainees. In the future, I hope to continue pursuing research to contribute to academia and give back to society.

Report on Science and Technology Festa 2013

NICT ran an exhibit at the "Science and Technology Festa" held March 16 and 17, 2013 at Kyoto Pulse Plaza in Kyoto Prefecture. In order to raise awareness of science and technology for young people, future leaders in science and technology, this event was held under the auspices of 16 organizations including seven ministries such as the Cabinet Office, Ministry of Internal Affairs and Communications, Ministry of Education, Culture, Sports, Science and Technology, and NICT. Over two days, the event received approximately 6,000 visitors.

NICT exhibited the cyber attack observation/analysis/countermeasure system "nicter" now being researched and developed in order to observe, analyze, and promptly respond to various security threats that occur in cyberspace, where visitors saw the observation and analysis situation of cyber attacks in real time.

On the first day of the event, YAMAMOTO Ichita, Minister of State for Okinawa and Northern Territories Affairs, Science and Technology Policy, Space Policy, the Cabinet Office, visited the NICT's booth. Many visitors were drawn to nicter which can monitor cyber attacks in real time, and made comments such as, "I was surprised that there's this many attacks in real time" and "Now I understand the importance of security measures." In addition to enhancing understanding of the importance of security measures, we succeeded in introducing network security research and development conducted at NICT to many people.



Visit by Minister YAMAMOTO Ichita (left)

The demonstraton of nicter that received much attention from visitors

Announcement of a change of the President

We hereby announce that the President of NICT has changed as follows.

April 1, 2013 onwards: Dr. SAKAUCHI Masao

Former Director General, NII (National Institute of Informatics)

Until March 31, 2013: Dr. MIYAHARA Hideo

NICT Headquarters Facility Tour

Since April 2013, NICT has been holding guided facility tours on research activities conducted in institutes at the headquarters.

◇ **Date**

Every Wednesday 13:30–15:00

Tours will not be held on national holidays, New Year holidays (12/29–1/3), and when NICT events are held.

◇ **Capacity**

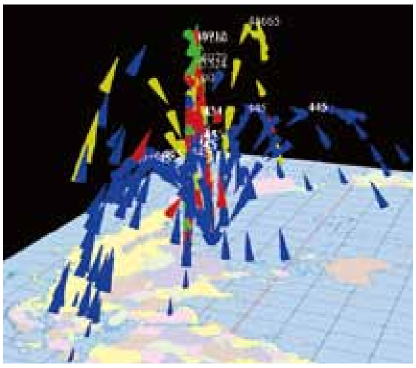
20 visitors

(Pre-registration is required. First-come, first-served basis.)

◇ **Tour Content**

- NICT introduction video (15 min.)
- Guided visit of exhibition room
- Introduction to research on cybersecurity technology (An Incident Analysis Center "nicter")
- Introduction to research on space-time standards technology (Decision/maintenance/dissemination system of Japan Standard Time)
- Introduction to research on electromagnetic wave sensing technology (Polarimetric and Interferometric Airborne Synthetic Aperture Radar "Pi-SAR2")

※Tour content is subject to change.



nicter

Japan Standard Time

Observation image using Pi-SAR2

◇ **Application**

After downloading and filling in the application form from the NICT website, please apply via email to the reservation request address.
For details, please visit the NICT website.
http://www.nict.go.jp/

◇ **Inquiries**

Tel: +81-42-327-5322
(Weekdays 9:00–17:00)

Email: nict-tour@ml.nict.go.jp

Information for Readers

The next issue will feature research and development of "disaster-resistant information and communications technology" that NICT is engaging in based on experience with the Great East Japan Earthquake.

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〈Recycled Paper〉