National Institute of
Information and Communications Technology

NICT NEWS

No.451 APR 2015

FEATURE

Constructing Japan Standard Time

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Cover Photo
The measurement system for Japan Standard Time. The signals of cesium atomic clocks in the clock rooms are constantly measured to generate the Japan Standard Time and standard frequency. The main components that reinforce reliability are in triplicate, and the status of each part is constantly monitored.

A New Start as a National Research and Development Agency

President

Dr. Masao SAKAUCHI

The National Institute of Information and Communications Technology (NICT) began a new phase as a National Research and Development Agency on April 1.

National Research and Development Agencies System was created to promote the world's highest level of R&D and to produce the greatest results, and NICT, together with other research and development agencies, has transitioned from being an Incorporated Administrative Agency to a National Research and Development Agency, as an exclusive organization specializing in the field of information and communications.

Its main mission has not changed, that of advancing research and development in information and communications technology, which is a driving force for growth in Japan, and helping to realize a prosperous, safe and secure society. As a new research and development agency, however, it is required to maximize its R&D results and to clarify what and how the R&D contributes to finding solutions to the many societal issues Japan faces today.

Because of this, R&D activities that are both far-sighted and based on open innovation are important. I also believe that as a public research agency, a major mission of NICT is to form and develop a research base, collaborating among enterprises, universities, and other research agencies, each bringing technologies at which they are skilled and creating new value. In doing so, industry integration will be an important keyword, creating new value through integration of information and communications with various other fields such as disaster prevention, agriculture, transportation and infrastructure. NICT is gathering ICT such as big data and sensor systems, nurturing technologies that contribute to society, building a base for innovation in social ICT, and creating a circle of cooperation among industry, academia, and government through these activities.

It is also important that Japan plays a leadership role in information and communications R&D presumed to expand globally, and NICT must always conduct its activities with a global perspective as part of that. We will be effective in promoting global activities, strategically developing global alliances, promoting collaborative R&D with US and Europe, establishing research collaboration organizations with research agencies in the ASEAN region, and forming international cooperation in multinational projects.

Directions for information and communications research in Japan are also being discussed actively at the Ministry of Internal Affairs and Communications and other areas of government. NICT will continue to drive R&D in this field in Japan, taking a medium-term perspective, and will contribute broadly to society through those efforts. I would like to ask for your continued understanding and cooperation in these efforts.

Interview

Providing Precise Time and Frequency Standards for an ICT Society

Technology supporting everything from daily life to leading-edge science

Yuko HANADO
Director of Space-Time Standards Laboratory, Applied Electromagnetic Research Institute
After completing a Master's course, joined the Communications Research Laboratory, Ministry of Posts and Telecommunications (Currently NICT), in 1989. Engaged in research regarding cosmic radio wave observations, the standard time system, and construction of the atomic time scale. Ph.D. (Engineering).

On July 1, a leap second will be added for the first time in three years.

A leap second will be inserted simultaneously around the world. In Japan, this is administered by the NICT Space-Time Standards Laboratory, Applied Electromagnetic Research Institute. Today, in the Internet era, the role of marking time precisely is becoming even more important. We spoke with Yuko HANADO, Director of the Laboratory, about how Japan Standard Time, and International standard time are created, and how high-precision time services operate.

Atomic Clocks: The basis for standard time

— Normally we just think of time in terms like, "Oh, it's time to get up," and we have very little awareness of what time actually is, but how is it that precise time is obtained?

HANADO In the past, the length of one day was based on the rotation of the earth, and the length of one second was determined by dividing it into small parts. However, as observational technology began improving around the middle of the 20th century, we realized that the rotation of the earth actually is not particularly stable. In 1967, a length of time based on a transition frequency of a cesium (Cs) atom was defined to obtain a more accurate second. One second is now defined as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of a cesium 133 atom. This departure from a time definition based on astronomical observation was an historical turning point. The length of one second based on the rotation of the earth was accurate to about eight decimal places, but the definition based on the cesium atom transition frequency is accurate to more than 15 decimal places. This accuracy is achieved using equipment called a cesium atomic clock.

Creating an accurate second with the cesium primary frequency standard

— What sort of equipment is an atomic clock?

HANADO An atomic clock is a device that extracts a particular transition frequency from an atom. To extract the frequency accurately, the atom must be kept in an extremely stable state, which the equipment achieves using vacuum, quantum electronics, ultra-stable laser and other advanced technologies. It is called an atomic clock, but its actual function is to oscillate accurately at a specific frequency (it does not mark particular time), so it is also called a frequency standard. In particular, equipment that implements the frequency that is the basis for the definition of the second is called a primary frequency standard.

How Standard Time is created

— Is the Cesium primary frequency standard the basis for standard time?

HANADO Global standard time is created by a somewhat complicated mechanism (Figure 1). First, a highly-stable free atomic time scale, called Echelle Atomique Libre (EAL), is created by clock ensemble, which is a weighted average of atomic clock data from around the world. Currently, over 400 clocks from around the world participate in EAL, including cesium atomic clocks at NICT. The International Atomic Time (TAI) system, which is the basis for standard time, is derived by applying precision frequency corrections from a Primary frequency standard to this EAL. EAL removes any wobble from individual atomic clocks, maintaining continuity and stability, while the primary frequency standard corrects the length of one second. This creates a mechanism that produces a stable and accurate TAI.

The primary frequency standard was developed in research facilities, and currently

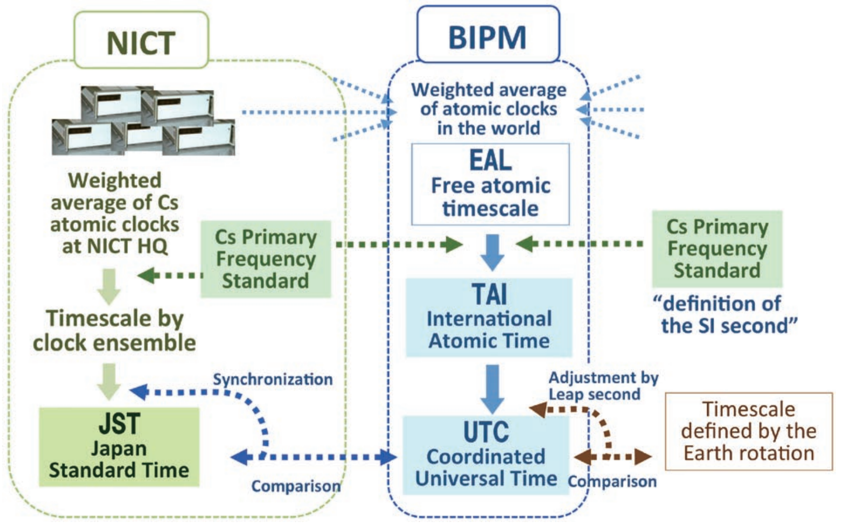


Figure 1 Mechanisms creating standard time

there are fewer than 20 operating in the world. NICT independently developed and operates one of these, called NICT-CsF1 (Figure 2). The Bureau International des Poids et Mesures (BIPM) in France is an international agency that gathers atomic clock data that is the basis for EAL as well as primary frequency standard data from around the world once each month and calculates TAI.

■Coordinated Universal Time

── Is TAI, which is created using many atomic clocks, the same as international standard time?

HANADO No, there is actually one more step in creating international standard time. For people, who live on the earth, it is extremely important to have time that corresponds to the rotation of the earth (world time), or equivalently, the movement of the sun. But atomic clocks continue to run regardless of the rotation of the earth and this leads to some discrepancy between atomic clocks and world time. So, the length of one second is set using atomic clocks, but a time system was created to adjust the time by one second if the cumulative difference with world time will exceed one second. This time system is called Coordinated Universal Time (UTC). UTC is currently used as standard time in the modern world.

Adjustments to add or remove a second are called leap seconds. The rotation of the earth is not predictable, so observations are made, and based on the results, a decision is made every six months when leap-second adjustments will be made. As you may already know, this leap second on July 1 will be the first leap second in three years.

── So standard time is decided, not only based on atomic clocks, but also involving the rotation of the earth.

Figure 2 NICT-CsF1 cesium fountain primary frequency standard

■Measuring the rotation of the earth

── Then measuring the rotation also needs to be precise, doesn't it?

HANADO In the past, the length of one day was determined by observations of the meridians. One day was measured as the time from when the sun passes its zenith till passing it again the next day (actually, the fixed stars rather than the sun were observed). Through the development of a type of space geodesy called Very Long Baseline Interferometry (VLBI), the accuracy of measurements of the earth's rotation has increased dramatically since the 1970's. Because of this, changes in not only the rotation, but also the wobble of the earth can be detected very accurately.

With VLBI, the signal from a distant quasar (radio star) is received by radio telescopes at separate locations, and by converting the differences in arrival time to a distance, the distance between the observation locations can be computed to give their positions relative to the quasar. This technology was only possible with the implementation of atomic clocks, which enable the arrival times at the distant stations to be compared with high precision. A single observation is roughly 1,000 times more precise than a meridian observation, but there are fewer quasars that can be used for observations than for meridian observations, so the net increase in precision is roughly two orders of magnitude.

In fact, the NICT Kashima Space Technology Center is the birthplace of VLBI technology in Japan, and has been making observations for nearly 30 years. The Kashima VLBI observation data also contributes to the international network observing the earth's rotation (Figure 3).

INTERVIEW

Providing Precise Time and Frequency Standards for an ICT Society

Technology supporting everything from daily life to leading-edge science

Figure 3 Kashima 34 m antenna used for VLBI observations

Standard time in each country

— Is Japan Standard Time the same as UTC?

HANADO UTC is the time at the prime meridian, and each 15 degrees of longitude produces a one hour time difference. Each country adds a time difference corresponding to its longitude to UTC and uses that as its standard time. Japan Standard Time adds a time difference of nine hours to UTC, corresponding to 135 degrees east longitude (which goes through Akashi City).

In fact, TAI and UTC cannot be used to answer the question, "What time is it now?" because they are virtual time systems. TAI and UTC for this month are not calculated till next month, and results are only calculated at intervals, one result every five days. For this reason, standards organizations in countries with advanced technology prepare and supply a concrete standard time, continuously and in real-time, that can be used in response to "What time is it now?"

NICT activities

— So this is one of NICT's roles in Japan?

HANADO Yes. NICT headquarters (in Koganei City, Tokyo) operates 18 cesium atomic clocks (Figure 4), counts oscillations to create an ensemble clock timescale, attaches a UTC+9-hour label, and supplies it as Japan Standard Time. An international link is needed to compare against UTC and participate in TAI, so high-precision time comparisons are done regularly through satellite relays. Comparisons are done with precision of less than one billionth of a second.

Japan Standard Time is supplied to all of Japan through various services. Long-wave band standard signals are transmitted throughout Japan from the transmission Station (40 kHz) at Fukushima and the transmission Station (60 kHz) in Kyusyu. Radio clocks receive these signals and set the time accordingly. The time is also provided through telephone lines (Telephone JJY), and this is used by communications carriers and broadcasters. Besides these, time can be set over networks using the NTP service, which provides time information to time business services used by applications such as e-commerce. There are also services

Figure 4 The cesium atomic clocks that form the basis for Japan Standard Time

that correct frequencies using the national frequency standard.

Figure 5 Visitors waiting for the inserted leap second and the clock display at the front of NICT headquarters (July 1, 2012)

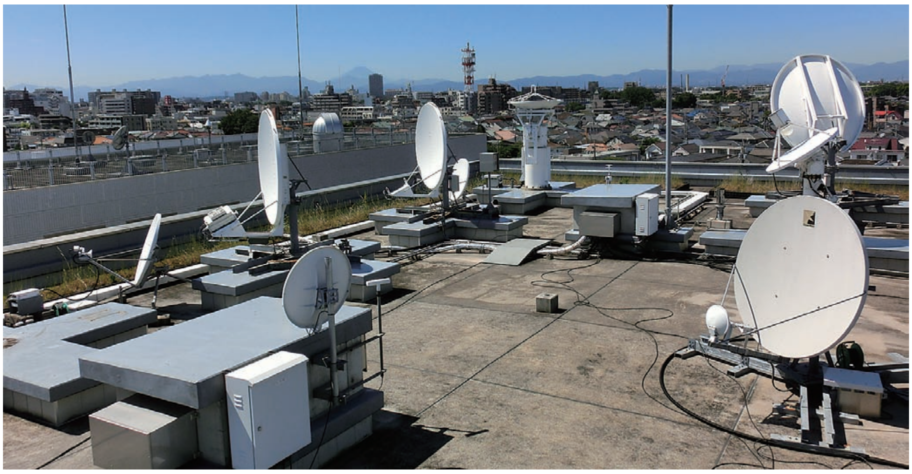


Figure 6 Two-way satellite antenna group for comparing time and frequency (Roof of Building 2, NICT headquarters)

■Cautions regarding leap seconds

── Will a leap second be inserted in these services?

HANADO Yes. We will be inserting a leap second, so NICT will add one second after 8:59:59 JST in all time services we provide. There are various ways this will appear on clocks, but on the clock at the front of NICT headquarters, it will appear as "60 s", which is not normally seen (Figure 5).

Transmitters of the service signals must reliably insert the leap second, but care must also be taken when receiving it. For example, if time adjustments on radio clocks are done periodically, the time will be one second off, until the next time adjustment on the day of the leap second. Also, it may be necessary to check that control programs for various types of system can operate correctly with insertion of the leap second. It may be safer to check how and at what time any devices you are using adjust the time before hand.

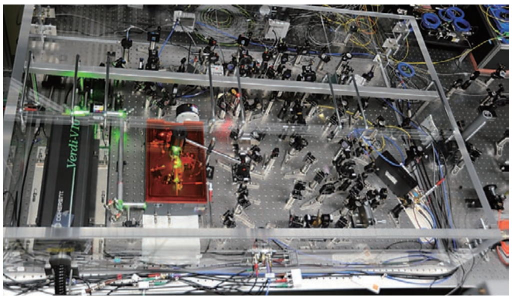
■Future Prospects

── Can I ask about activities for the future, looking forward?

HANADO Regarding Japan Standard Time, we are working on a distributed structure to increase reliability. We are attempting to combine atomic clocks in various regions to create Japan Standard time, and the first station, at the Advanced ICT Research Institute in Kobe City, Hyogo Prefecture, is currently in preparation. We are also developing new time provision technologies, and technologies for measuring frequencies in undeveloped frequency bands (THz).

This development is close to practical technology, but in parallel, we are also researching ultra-high precision technologies. For the next generation of atomic clocks, we are developing an optical frequency standard that may replace the definition of the second. The second is a unit of outstanding high precision among the seven quantitative units. For example, the best among the other independent units is measured to eight decimal places, but the second has reached a precision of 16 decimal places. If an optical frequency standard is used, this precision should be improved by a further two or three decimal places. However, by itself, this sort of high-precision frequency standard would be wasted. To use and share a frequency standard around the world, technologies to compare and transmit them are essential. There are only a few laboratories in the world with top-class capabilities to develop both a frequency standard and technologies to compare and transmit it, and this is a major strength of NICT (Figures 6, 7). NICT has demonstrated the highest precision in the world with technology for comparing signals by satellite, and is conducting world-leading technical development on new techniques, applying VLBI technology to compare frequencies.

Our activities involve creating, measuring and supplying accurate time and frequency. Accurate time and frequency is important information supporting infrastructure in society, and one of our important missions is to contribute to this basic infrastructure technology. Another of our roles is to develop advanced technology. Realizing atomic clocks opened the door to high-precision measurement. Study of the elemental technologies leads to breakthroughs on the limits of measurement precision. Both VLBI and GPS are technologies that would not be possible if atomic clocks had not been developed, and leap seconds are a result of standard time due to atomic clocks combined with measurement of the earth's rotation, in which VLBI plays a leading role. It is difficult to imagine why we need a clock that is accurate to within one second every several hundred million years, but I would be very happy if you could keep in mind that the appearance of this high-precision time and frequency technology is the root of many things, from conveniences in everyday life, to wonderful and inspiring things in space development.



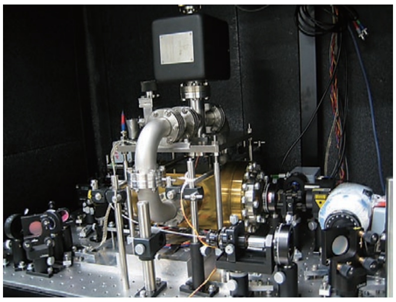


Figure 7 Equipment central to ultra-high precision optical measurement (left: optical frequency comb, right: narrow line-width laser)

Atomic Fountain Primary Frequency Standard

The only device able to realize the current definition of the second

Motohiro KUMAGAI
Senior Researcher, Space-Time Standards Laboratory, Applied Electromagnetic Research Institute

After completing a doctoral course, joined the Communications Research Laboratory, Ministry of Posts and Telecommunications (currently NICT) in 2000. Since then, engaged in research on frequency standards, including primary frequency standard development and reference signal distribution using optical fiber. Ph.D. (Science).

Atomic clocks are based on the principle that the differences between discrete energy levels in atoms, molecules and ions are fixed constants (as long as the fundamental physical constants remain unchanged), and they use the spectrum emitted by an atom as a frequency standard. This idea was proposed in the first half of the 20th century, but was not actually implemented till half-way through the 20th century, when the first cesium (Cs) atomic clock was developed in the United Kingdom in 1955. Measurements using a cesium atomic clock can be done much more quickly than astronomical measurements, and much more accurately (approximately 10 billion times more accurate than capabilities at the time), so in 1967, the second was redefined to be based on a transition frequency of a cesium atom.

Principles of primary frequency standard

The definition of the second can be expressed in one sentence (see p. 2 of this issue), but behind this definition are assumptions regarding the conditions, including a cesium atom at rest, a temperature of absolute zero (0 K), no magnetic or electric fields, no gravitational effects, and no collisions with other atoms or molecules. However, it is not possible to observe a signal under these conditions in a real experimental system. The resonance frequency of the cesium atom is somewhat shifted due to the external environment, but a *primary frequency standard* is a specialized device designed to evaluate quantitatively and correct for all frequency shifts.

History of primary frequency standard development at NICT

The performance of a primary frequency standard depends heavily on extracting signals with small deviations from the resonance frequency (i.e., signals with a narrow line width). The longer the atom is exposed to the electromagnetic wave, the narrower the line-width of the signal that can be observed, but it is difficult to expose a moving atom continuously, so a method to do this was invented, called Ramsey resonance*1. When an atom is exposed to electromagnetic waves for two short periods under suitable conditions, the same effect as when exposed over a longer period is obtained, and the inverse of the exposure time interval is the resonance signal line width. This revolutionary method is still the core technology used for cesium primary frequency standards.

The first cesium primary frequency standard was of the hot-beam, magnetic-selection type, in which heated cesium atoms are emitted horizontally, exposed to electromagnetic waves in two cavities placed along the beam path, changing their state due to Ramsey resonance, and then selected by magnetic gradient. Use of hot beam type clocks later transitioned to the optically pumped type, which played a leading role until the atomic fountain type appeared. NICT also developed magnetic selection type (CRL-Cs1) and optically pumped

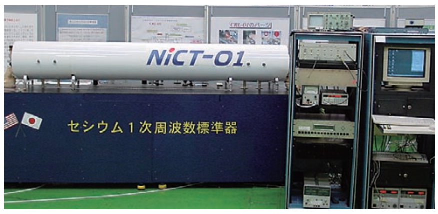


Figure 1 NICT-O1

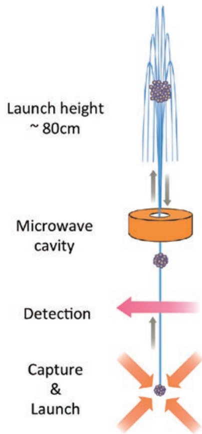


Figure 2 Schematic diagram of the atomic fountain primary frequency standard

*1 **Ramsey resonance**: Discovered by Dr. Norman Foster Ramsey. The physical phenomenon that when an atom is exposed to electro-magnetic waves twice, if the state of the atom does not change, it behaves similarly to when exposed continuously by electro-magnetic waves. Awarded the 1989 Nobel Prize in physics.

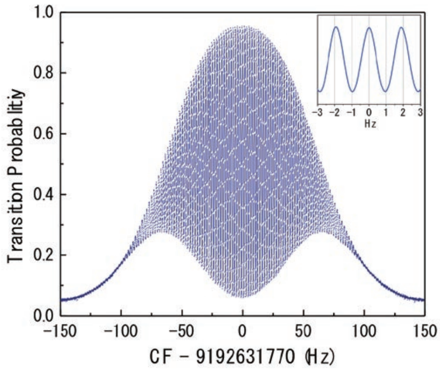


Figure 3 Observed Ramsey signal
The center frequency of the fringe pattern is used as the basis of the definition of the second.

type (CRL-O1 → NICT-O1) clocks, and participated in creating International Atomic Time (TAI) until 2006.

Atomic fountain primary frequency standard

In the primary frequency standards using a hot beam, atoms move quickly, at 200 m/s, so there are fundamental limits in time intervals that can be created. Thus, the atomic fountain type was developed, making use of laser cooling*[2]. In the atomic fountain, cesium atoms are captured at one location and cooled to an extremely low temperature of several μK, using laser cooling. The group of captured cesium atoms is then slowly launched vertically using laser light and allowed to fall due to gravity. If a cavity is placed along this path, when the cesium atoms pass through the cavity, they are exposed to electromagnetic waves twice; once while rising, and once while falling, resulting in Ramsey resonance. With this mechanism, the motion of the atoms resemble a fountain, so it is called an atomic fountain. The atomic fountain can create longer intervals than a hot-beam type, so most current cesium frequency standards are of this type (Figure 2).

NICT-CsF1 and CsF2

Primary frequency standards must be built to evaluate all conceivable causes of frequency shift, and the planning and design of practical systems is at the discretion of the developers. Thus, to implement a design as usable equipment, many advanced technologies must be integrated at a high level, such as vacuum, laser, and control technologies. At the Space-Time Standards Laboratory, we designed and developed an original atomic fountain primary frequency standard as a successor to the hot-beam-type standards. We identified issues and problems using a prototype (on display in the exhibit room at NICT headquarters), and through many design changes and much trial and error, finally completed NICT-CsF1 (Figure 2 on p. 3 of this issue). By implementing the operating principles of the atomic fountain, we observed Ramsey signals with line widths of less than 1 Hz (Figure 3), we were able to evaluate more than ten of the causes of frequency shift, and we achieved accuracy of less than one second in 20 million years of operation. NICT-CsF1 was the first standard to be inspected by the primary frequency standards working group (composed of specialists from the major standards organizations of the world), and since 2006 has been internationally recognized as a primary frequency standard able to contribute to corrections of TAI.

Development of a second, new type, of primary frequency standard, CsF2, is progressing to further improve accuracy (Figure 4). CsF2 uses a different method of laser cooling from CsF1 and is expected to increase accuracy by almost an order of magnitude. With two frequency standards, operational availability should improve, and by comparing CsF1 and CsF2, causes of frequency shift can be investigated and further increases in accuracy can be expected.

Future prospects

The cesium atomic clock transition is likely the most studied transition in the world, and additional physical affects to be evaluated are still increasing (Table 1). When a new cause of frequency shift is proposed, the systems must be improved in order to evaluate the amount of shift quantitatively. We are also improving our equipment whenever a new cause of shift arises in order to further improve accuracy.

Table 1 Causes of frequency shift that need to be evaluated (as of April, 2015)

Physical effect
2nd Zeeman
Collision
Blackbody radiation
Gravity potential
Microwave leakage
Microwave purity
Cavity pulling
Rabi pulling
Ramsey pulling
AC stark
Distributed cavity phase
2nd Doppler
Microwave lensing
Majorana transition
Background gas

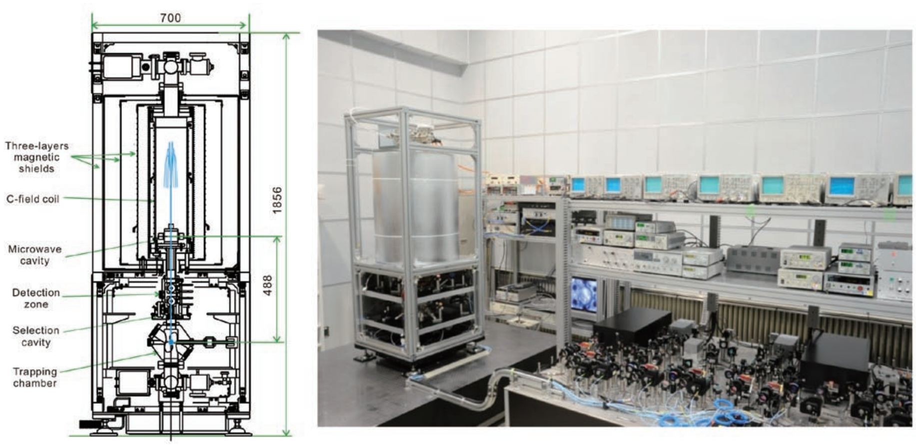


Figure 4 Cross section of the NICT-CsF2 unit (left), and the NICT-CsF2 system (right)
In the right figure, the vacuum chamber is on the left, and the optical systems for atom capture, launch and detection are on the right. Laser light is sent by optical fiber. Behind the main unit are microwave synthesizer and other equipment.

＊2 **Laser cooling**: A method for using the power of laser radiation to stop the motion of atoms by exposing them to laser light from six orthogonal directions. Awarded the 1997 Nobel Prize in physics.

VLBI Antennas Applied for Space and Time Measurements

Mamoru SEKIDO
Associate Director of Space-Time Standards Laboratory, Applied Electromagnetic Research Institute

After completing a doctoral course, joined the Communications Research Laboratory, Ministry of Posts and Telecommunications (currently NICT) in 1991. Engaged in research on VLBI Correlation Processing, pulsar VLBI observations, and e-VLBI technology using high-speed networks. Ph.D. (Science).

Space geodetic technology such as GPS has now come into use in everyday life as a basis for measurement and positioning. Fundamental to them are standard coordinate systems for the earth and the celestial sphere, supported by other geodetic technology such as VLBI*1 and SLR*2, of which users are generally not aware. For VLBI, research agencies in various countries collaborate in taking measurements, and fulfill the role of determining the standard global coordinate system to millimeter accuracy.

Introduction to VLBI

On July 1 of this year, clocks around the world will be adjusted by one leap second. This will correct a difference between UT1 time, which is based on the rotation of the earth, and the time marked by atomic clocks. VLBI is currently the best technology able to measure the rotation of the earth with long-term stability.

In addition to making accurate spatial measurements, VLBI is also used to compare the advance of atomic clocks that are far apart. Currently, in our group, we are developing technology that is a new application of VLBI, to compare frequencies of distant atomic clocks with high precision.

VLBI is a technology in which multiple antennas are used to receive radio waves from a celestial radio source, each using an independent atomic clock as the source of a reference frequency. These signals are then interfered with each other. Interference refers to the phenomenon in which, when waves are superimposed on each other, areas of amplification and attenuation appear. In radio astronomy, a method called radio interferometry is used to increase the resolution of observations of celestial bodies. Signals are received with multiple antennas simultaneously and interfered with one another utilizing the wave properties of radio waves. The resolution of observations increases when the antennas are separated further, but to interfere the signals with each other, the phase information must be recorded, and to do so, a reference frequency must be provided to each antenna. Thus, the distance between antennas was limited by the length of the cable used to transmit the reference frequency, placing an upper limit on resolution. With VLBI, the need for a cable between the antennas is eliminated by using a hydrogen maser atomic clock as a frequency source at each of the locations, so that radio interferometry observations can be configured spanning continents, or even satellites in space. This has been realized through the integration of advanced, precise atomic clocks and digital technology.

VLBI is a radio astronomical observation technology that has more than 100 times spatial resolution of the Hubble Space Telescope and represents humankind's most powerful "eyes" on space. It is also used to make precise measurements of distances between continents, and of the rotation of the earth (geodesy), and for high precision orbit determination of planetary probes and other spacecraft.

VLBI at NICT

The Kashima Antenna Facility of the Radio Research Laboratory of the Ministry of Posts and Telecommunications (currently the NICT Kashima Space Technology Center) is the birthplace of VLBI technology in Japan. At the time, the Radio Research Laboratory integrated receivers developed for satellite communications, large-scale parabolic an-

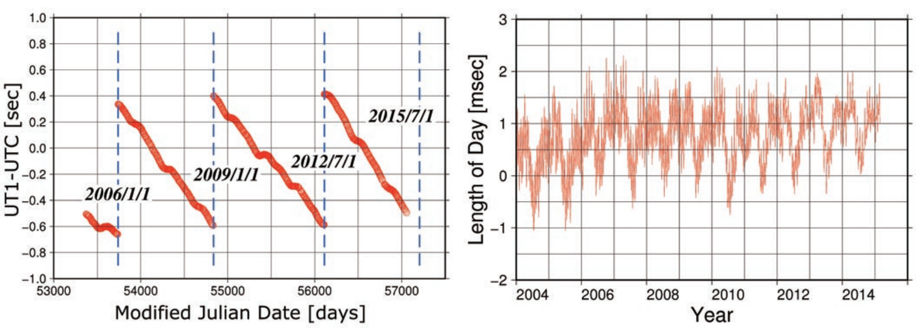


Figure 1 Leap-second adjustments and fluctuation in the length of one day
Leap-second adjustments to keep the difference between UT1, based on the earth's rotation, and UTC to less than one second (left). The length of one day fluctuates constantly and is difficult to predict (right). The earth's rotation (=UT1) must be measured by observation.

*1 **VLBI**: Very Long Baseline Interferometry
*2 **SLR**: Satellite Laser Ranging

tennas, and atomic clock technology used for Japan Standard Time in order to implement VLBI. Technologies and personnel cultivated at NICT have supported radio astronomy observations at the National Astronomical Observatory of Japan and VLBI observations for the Institute of Space and Astronautical Science (JAXA) deep space probe, and have been also active in geodetic observations at the Geospatial Information Authority of Japan and geosynchronous satellite orbital control for private satellite operators. In addition to past achievements, such as the world's first VLBI observations in Antarctica and detecting the plate motion of the earth's surface, the VLBI observation system developed at NICT is also being used by observatories within and outside Japan and is playing a leading role in development of a new, wideband VLBI technology described below.

New technology application: Comparing remote frequency standards using broadband VLBI

The ability to accurately compare the frequencies of atomic clocks in various countries is important for maintaining Universal Coordinated Time (UTC) and for developing a new definition of the second. VLBI has advantages that earlier methods do not, including ability to compare differences in clocks at multiple locations on the globe at once with a single observation, and that it does not depend on satellite orbital information. We are implementing frequency comparison between inexpensive, portable, small aperture antennas relaying to large antennas, using a new technology that acquires a broadband signal. As a demonstration, we installed 1.6 m diameter small antennas at the National Metrology Institute of Japan at the National Institute of Advanced Industrial Science and Technology (NMIJ, Tsukuba City, Ibararaki Prefecture) and at NICT headquarters (Koganei City, Tokyo), and conducted experiments comparing atomic clocks at each location (Figure 2).

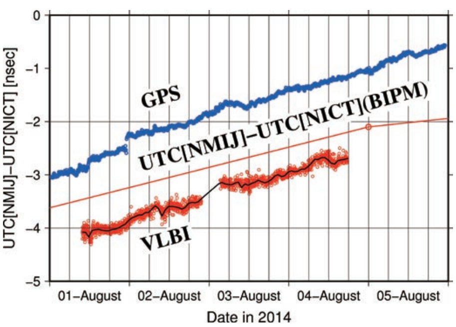


Figure 2 Results of comparing UTC[NMIJ]–UTC[NICT] measured at a frequency of 8 GHz using compact antennas installed at NMIJ and NICT

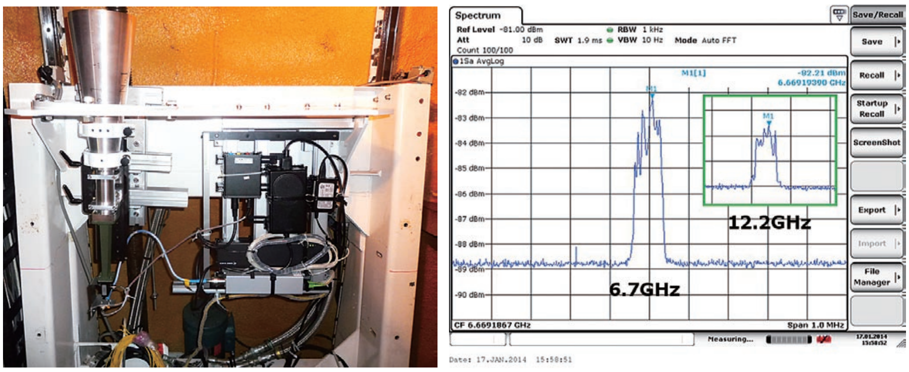


Figure 3 Wideband feed attached to 34 m antenna (left), successfully received 6.7 GHz and 12.2 GHz methanol maser emissions from radio source W3OH (right)

As part of developing the broadband observation technology, we developed an original design for a narrow-beam broadband receiver feed (Figure 3), which had been difficult earlier. Equipped with this feed, our 34 m antenna has become the largest parabolic antenna in the world capable of observations spanning the continuous range from 6.5 to 14 GHz. The ability to receive broadband signals is also very attractive for radio astronomy. Methanol, a type of alcohol, is known be present in star-forming regions of space, and to produce natural maser emissions*3 at frequencies of 6.7 GHz and 12.2 GHz. The 34 m antenna equipped with the new wideband receiver was successful in receiving a signal including both of these frequencies, separated by approximately one octave, simultaneously (Figure 3). This promises to advance our understanding of the evolution of stars in ways not possible in the past.

World's first successful ultra-wide-band observations

Even with the broadband observations, simply obtaining individual 1 GHz bandwidth signals does not increase the accuracy of measurements much. By synthesizing the phase of the broadband signals, the accuracy of delayed measurements increases dramatically. However, it is very difficult to synthesize signals as waves when they are separated in frequency by several GHz or more. This is because, with conventional data acquisition methods, different signal paths are used for each band, frequencies are converted, and each band is sampled separately, making it difficult to have uniform timing and amplitude between the signals. Accordingly, we did not partition the signals or convert frequencies, but used a new data acquisition method called direct sampling, which uses a high-speed A/D converter able to sample the signal directly, including the high-frequency components. This reduced signal scattering due to observation equipment. In test observations in January, 2015, we succeeded in the world's first phase synthesis of an 8 GHz ultra-wide-band signal (Figure 4). The theoretical accuracy of these delay measurements was 60 femto-seconds (the time for light to travel approximately 20 microns), which is extremely high. We will verify the accuracy of measurements using these ultra-wideband observations and conduct comparisons to verify atomic clocks around the world, starting with NICT–NMIJ.

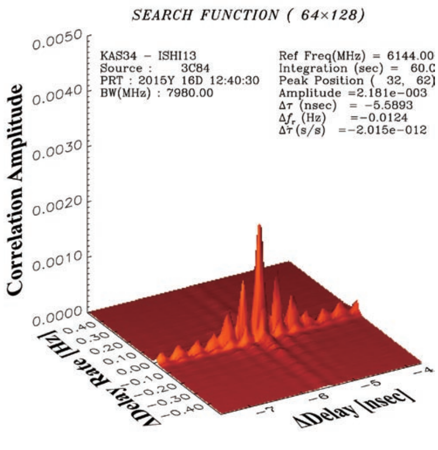
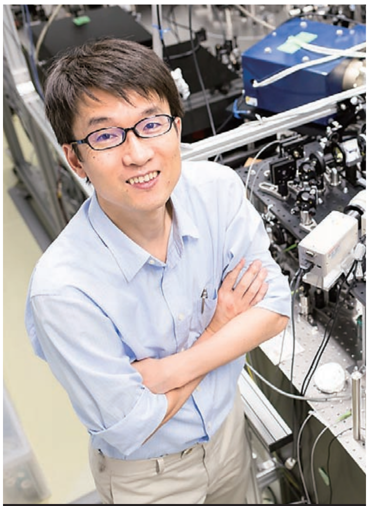


Figure 4 Cross-correlation function obtained from ultra-wideband 6–14 GHz VLBI observations and signal synthesis

*3 **Maser emission**: A phenomenon in which a highly directional electromagnetic wave is emitted at a frequency determined by the substance. When this phenomenon occurs at microwave frequencies it is called a maser emission, and when it occurs at light frequencies, it is called a laser emission.

Frequency Standards

Knocking a door to the next after staying for half-century



Tetsuya IDO
Research Manager, Space-Time Standards Laboratory, Applied Electromagnetic Research Institute

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

It is often said that lasers had the strongest impact among various innovations realized in the last century. The monochromatic light from lasers caused revolutions in a wide range of fields, with records giving way to CDs, and telephones moving to fiber-optic communications. Such a considerable change may also happen in the field of precision clocks.

Are clocks also entering an optical era?

Nearly half a century ago, the second was defined by a transition of cesium atoms, and the uncertainty of the cesium clocks has now reached approximately one part in ten quadrillion. On the other hand, there has been active research since the 1980s on optical clocks, which generate a light frequency based on an atomic optical transition, and progress has gradually accumulated. Ten years ago, a technology for converting optical frequencies to microwaves (the optical frequency comb) was developed, so that optical frequencies emitted by optical clocks could be accurately converted to microwave frequencies, and very recently, several optical clocks with precision greater than cesium atomic clocks, at more than 17 decimal places, were finally achieved. Not only are optical clocks accurate, their optical output signal frequencies are tens of thousands of times higher than microwave signals, with the advantage that finer time and frequency measurements can be done in the same time. This means that the current definition of the second in the International System of Units (SI), based on cesium, is no longer the best representation of time, and discussion regarding the redefinition of the second has begun in the community of time and frequency standards.

Two major types of optical clock: lattice clock and single-ion clock

There are two possible methods of optical clock for implementing the definition of the second: the optical lattice clock, which uses multiple neutral atoms, and the single ion clock, which uses a single ion. The highest performance for both of these exceeds that of a cesium atomic clock, yielding 18-decimal-place performance. The optical lattice clock is a Japanese invention, proposed in 2001 by

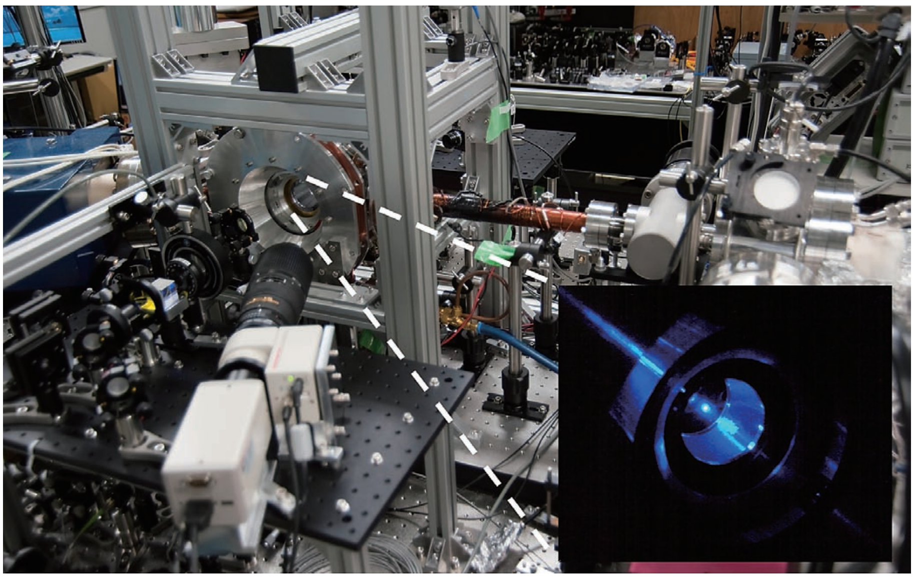


Figure 1 Atomic trap part of the strontium optical lattice clock
Strontium atoms laser-cooled and trapped in the center of a vacuum chamber are interrogated by exposure with a clock laser. The difference from the resonance is determined from the excitation ratio, and the laser frequency is adjusted to the standard frequency accordingly.

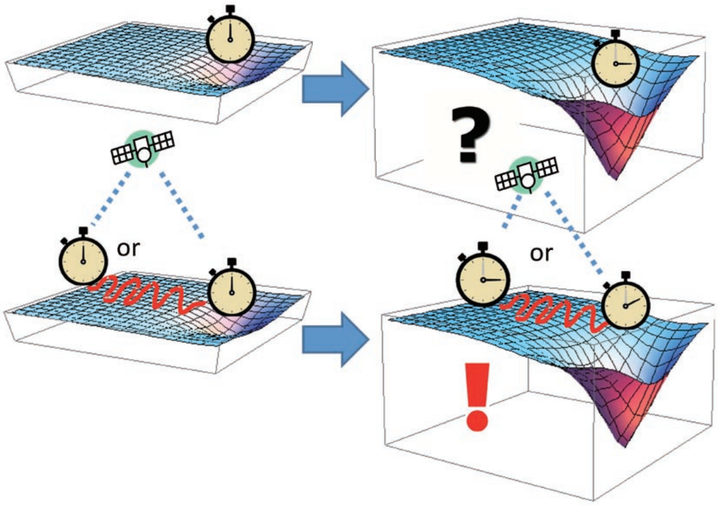


Figure 3 To use the advancement of a clock as a gravity sensor, two distant clocks must be linked. Even if gravity increases, it cannot be detected with only one clock, as shown in the upper figure. The clocks can only be used to sense gravity if they are separated by a distance but linked by optical fiber, satellite or other means, as shown in the lower figure.

Dr. Hidetoshi KATORI. This author has also been working on this subject since it was first proposed. The most significant feature of the optical lattice clock is that the signal is obtained from multiple atoms, so that the center frequency of the resonance can be determined in a short time, and as a result, the frequency does not fluctuate over short periods of time. On the other hand, the single-ion clock, which was proposed in the 1980's in Europe and the United States, showed better accuracy than the optical lattice clock until about 2013, and had advantages in that it could be built using fewer lasers, was more mobile, could be operated continuously for long periods of time and was easier to use in a variety of technical applications.

At NICT, we developed both types, a strontium optical lattice clock (Figure 1), and an indium ion clock (Figure 2). The strontium optical lattice clock has been recognized as a secondary representation of the second by the Comité International des Poids et Mesures (CIPM) since 2006. The secondary representations of the second are essentially candidates for a redefinition of the second in the future. Currently, seven different optical transitions have been identified, but strontium optical clocks are the most significant, with eight devices currently operating around the world. The optical lattice clock at NICT has been operating since 2011, currently has accuracy of within one second every 140 million years, and has been checked for consistency of frequency with other optical lattice clocks in and outside Japan using the link technology described below. Conversely, development of the indium ion clock only began in 2012, so while it promises accuracy of greater than 18 decimal places, it requires advanced technology to deal with ultra-violet. It is one of the most challenging optical clocks and has not been implemented anywhere yet.

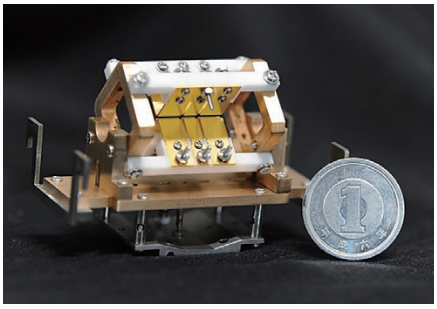


Figure 2 Trap electrodes used in the indium ion clock
Four wedge-shaped electrodes, each divided into three parts, surround a central gap where ions are trapped. These are exposed to a clock laser to get the difference from the resonant frequency.

Importance of link technologies

When developing high-precision clocks, the goal is not simply to produce a result for Guinness World Records. The stable one second generated by high precision clocks enables unprecedentedly minute fluctuations in time or frequency to be detected, and these may lead to new discoveries. Through development of high precision clocks, we hope to contribute to these innovations. To use a high precision clock, the clock signal must be transported to the location of what is being measured without losing accuracy. Also, the reliability of the clock can only be established by confirming its consistency with another remote clock of equal precision. When this is implemented at global scale, a redefinition of the second will be established. Considering these conditions, in addition to development of optical clocks, NICT is making efforts to link clocks at physically distant locations. In 2011, optical lattice clocks at NICT headquarters (Koganei, Tokyo), and the Hongo campus of the University of Tokyo (Bunkyo-ku, Tokyo), were connected by an optical fiber, and the signal generated by the clock at NICT was sent to the University of Tokyo, confirming for the first time that the frequencies between two institutes at distant locations agree to 16 decimal places. In this experiment, general relativistic effects were also detected due to the fact that NICT headquarters is located on the Musashino Terrace, 56 m higher in altitude than the University of Tokyo. Also, leading the world, we developed a high-speed optical clock frequency-comparison technology using communications satellites and in 2013, performed the first direct frequency comparisons of optical lattice clocks between continents with the Physikalisch-Technische Bundesanstalt (PTB) in Germany.

Unification of space and time demonstrated by optical clocks

This year is the 100th anniversary of establishing Einstein's general theory of relativity. Till now, relativistic theory has only been considered in areas quite distant from daily life, such as space or particle accelerators, but high-precision clocks require considering relativity, as demonstrated by the NICT–University of Tokyo link described earlier. Optical clocks also hold promise for use in detecting resources or the movement of magma within the earth by using fluctuations in the advance of optical clocks to perceive time and space fluctuations using the distribution of gravitational force. For these applications, any fluctuation in a high-precision clock cannot not be detected with just one clock, and a second clock at the same location would fluctuate the same way, so no change in gravity could be detected. Two or more high-precision clocks must be placed at distant locations, and a precision link must be established between them before such a technology could be realized (Figure 3). The Space-Time Standards Laboratory is continuing development on both technology to increase precision of optical clocks, and to link them together, and as our name indicates we are establishing next-generation frequency standard technologies that handle time and space as one.

Report on Kigyouka Koshien and Kigyouka Expo

1st day 2nd day

To encourage business in the field of information and communications, NICT is promoting the discovery and cultivation of the next generation of human resources aspiring to businesses utilizing ICT, including students at technical colleges, universities and graduate schools throughout Japan. NICT is also promoting expansion of business for local venture companies in the ICT field.

A part of these efforts are the "Kigyouka Koshien", in which students and young people selected from all over Japan compete with business plans, and the "Kigyouka Expo", which facilitates business matching to help promising local venture businesses in ways such as procure funding and expanding sales channels. These events were held on March 3 and 4, 2015, at KOKUYO HALL in Minato-ku, Tokyo. (See http://www.venture.nict.go.jp/ for details (Japanese only).)

Entrepreneur Support Office, ICT Industry Promotion Department

1st day
Kigyouka Koshien
March 3, 2015

Presentations of ICT related products and services from the 11 teams selected throughout Japan were held, and awards were presented, including the Minister for Internal Affairs and Communications (MIC) Award, the Jury's Special Award, special awards such as a "Luncheon with the CEO", from the 11 sponsoring enterprises, and the Best Mentor Award for ICT mentors who mentored recipients of the MIC award. Approximately 190 educators and students attended and there was lively exchange with many questions.

◆Minister for Internal Affairs and Communications Award

Team: HackforPlay
Representative: Daiki TERAMOTO (Ishikawa National College of Technology)
"HackforPlay"

HackforPlay is used as an educational resource, enabling users to change the game while playing it. Users learn how code they write affects the program in ways that are easy to understand within the game. It integrates well with earlier basic learning, and is easily introduced because it uses the Web. http://hackforplay.xyz (Japanese only)

◆Best Mentor Award **Kengo ITO,** Managing Director of Genuine Startups Ltd.

◆Jury's Special Award

Team: ScreenAIR
Representative: Keita YAMAZAKI (National Institute of Technology, Kagawa College)
"SCREEN feels AIR"

Recently, people from all generations, from children to adults, are enjoying games at game centers. There are products that have succeeded in creating a sensation, have deeply rooted popularity, and continue to generate profits. A popular example is Taiko no Tatsujin, with its characteristic input interface. The product we are proposing is a game based on a new type of input interface using wind.

FY2014 Kigyouka Koushien Participating Teams (in order of presentations)

① Capsule Cosme, Sae KATO (Yokohama National University)
② Panyanyan, Saki KOYAMA (National Institute of Technology, Toba College)
③ team Mizuki, Taisei IGARASHI (The University of Aizu)
④ Connect, Takeshi OTANI (Kinki University)
⑤ ScreenAIR, Keita YAMAZAKI (National Institute of Technology, Kagawa College)
⑥ MAKE Deals, Meiko Zhao (Digital Hollywood University)
⑦ Quintet, Shosei YAMAGUCHI (Meiji University)
⑧ Healthcare Technologies, Daisuke MATSUOKA (Ritsumeikan University)
⑨ MDNA, Ryosuke KUBOTA (Kinki University)
⑩ HackforPlay, Daiki TERAMOTO (Ishikawa National College of Technology)
⑪ Caramel Pudding, Rintaro IKUTA (Okinawa National College of Technology)

2nd day
Kigyouka Expo
March 4, 2015

Enthusiastic presentations were given by ten companies selected from throughout Japan, on topics related to expanding new businesses (products or services), including business collaboration, procuring funding, and securing human resources. Regional support organizations from each selected region also introduced initiatives in support of local ventures.

Awards were given after the presentations, including the Minister for Internal Affairs and Communications (MIC) Award, the Audience Award, and the Best Mentor award for ICT Mentors that mentored the recipient of the MIC Award. The regional support organization introducing the best initiatives also received Regional Support Group Award from the other regional support organizations.

Approximately 180 people attended from large enterprises, ICT companies in Tokyo, investment companies, and regional support organizations, and there was lively exchange with many questions.

◆Minister for Internal Affairs and Communications Award

Shinichiro MONOBE, CEO of ExMedio (Shikoku district: Kochi Prefecture)

"Hifumirukun"

Currently in Japan, there is often a need for non-dermatologists, who do not specialize in skin diseases, to diagnose them. Our service provides diagnostic support to doctors, allowing them to take a photo of the affected area using a smartphone and receive a correct diagnosis of the ailment from the service.

◆Best Mentor Award

Hisashi KATSUYA (Professional Connector/Painting Artist)

◆Audience Award

Katsunori SHIMOMURA, CEO of Enowa co.,ltd.

(Hokuriku district: Ishikawa Prefecture)

"The Sluice Gate Management Service for Rice Farmers"

This service uses IT and sensor technology to provide automated monitoring and water management in rice paddies for wet-land rice farmers. It is able to gather know-how, collecting water level and temperature information for use in cultivation. It is becoming more necessary as farmers age and the scale of agriculture increases.

◆Regional Support Group Award

Fukuoka Prefecture Ruby and Software Industry Promotion Committee

FY2014 Kigyouka Expo Presenters
(In order of presentation)

① GLOCALISM Inc. (Kanto district: Shonan Industrial Promotion Foundation)
② GOCCO. (Tokai district: Softpia Japan)
③ Crunchtimer Inc. (Chugoku district: Hiroshima Internet Business Society (HiBis))
④ Agri Future Co., Ltd. (Tohoku district: Miyagi Mobile Society (MiMoS))
⑤ Eyes, JAPAN Co. Ltd. (Tohoku district: Aizuwakamatsu City)
⑥ Enowa co., ltd. (Hokuriku district: Ishikawa Sunrise Industries Creation Organization (ISICO))
⑦ Fookell Co., Ltd. (Organizer conference of Shinshu Venture Contest)
⑧ INDETAIL Co., Ltd. (Hokkaido district: Hokkaido Mobile Content and business Council)
⑨ ExMedio (Shikoku district: Kochi Industrial Promotion Center)
⑩ Welmo, Inc. (Kyushu district: Fukuoka Ruby and Software Industry Promotion Committee)

The names of districts and regional support organizations are provided in parentheses.

Employment Information for FY2016

Permanent Researcher and Tenure-Track Researcher Positions

NICT is recruiting, broadly and without regard for age, for excellent and ambitious researchers to promote its R&D in information and communications technology.

We are actively hiring men and women of both Japanese and foreign citizenship.

Start date: April 1, 2016 (negotiable)

Fields
- **(1) Advanced networks**
- **(2) ICT security**
- **(3) Information analysis and services platform**
- **(4) Applied electromagnetic and remote sensing**
- **(5) ICT frontiers**
- **(6) Other innovative technologies on information and communications**

Number of positions: Ten or more Permanent Researchers or Tenure Track Researchers

Application deadline: Must be received by 17:00, May 22, 2015

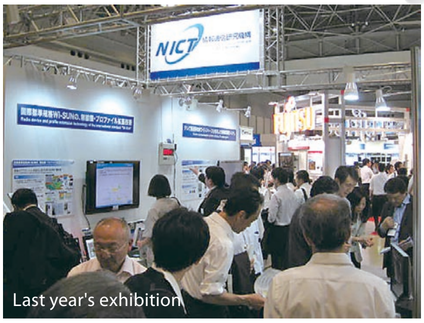
For details, see the Employment Information section (Permanent Researcher) on the NICT Web site:
http://www.nict.go.jp/employment/permanent/2016perm-kenkyu.html (Japanese only)
Inquiries Tel: +81-42-327-7304 E-mail: jinjig@ml.nict.go.jp

WTP2015

WIRELESS TECHNOLOGY PARK 2015

Co-held Exhibition: WIRELESS JAPAN 2015 and TRANSPORTATION SYSTEM EXPO 2015

May 27 (Wed.) to 29 (Fri.), 2015
At Tokyo Big Sight



Last year's exhibition

WIRELESS TECHNOLOGY PARK 2015 (WTP2015) is a special event focused on R&D in wireless technology, composed of an exhibition, seminars and academic sessions.

The main theme this year is "Social innovation evolved with wireless technology," and various plans to help attendees understanding the latest trends in wireless communication and wireless technologies have been prepared.

NICT will introduce the latest results from the Wireless Network Research Institute and the Social ICT Research Center through exhibits and presentations.

We invite you all to attend!

Hosted by: NICT, YRP R&D Promotion Committee, YRP Academia Collaboration Network
For details, see the WTP2015 Web page: http://www.wt-park.com/eng/

As of this issue, we have redesigned the layout and will publish six issues per year. The next issue will feature resilient ICT research, relating to the Third UN World Conference on Disaster Risk Reduction, held in Sendai in March.

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