Annual Report 2021

Research Institute of Electrical Communication
Tohoku University

Annual report of Research Institute of Electrical Communication 2021

Contents

1. Introduction

It is the mission of Research Institute of Electrical Communication (RIEC) to realize a new paradigm of communications that enriches people's lives. Communication is important in various ways in human society. Information communication technology (ICT) has been changing the way we deal with information drastically, overriding our biological limitations and expanding the world of communication from among people to among things as well as between people and things. Such ICT research is gathering attention for new normal after the coronavirus pandemic. RIEC is determined to work for future society with further advanced ICT, contributing to the welfare of human beings by opening up a new era of academically rooted innovation befitting a university.

The Japan's Sixth Science and Technology Basic Plan aims to realize Society5.0, which is a cycle of innovation toward a super-smart society. The plan sets out policies for strengthening the fundamental technologies that will support this, including cyber security, the "Internet of Things (IoT)," big data, artificial intelligence, and devices. It goes without saying that these research fields fall under the RIEC's scope of expertise and that the institute must play a leading role in furthering them. Meanwhile, universities are expected to conduct basic researches, some of which would create innovations that enriches the society. We have such examples in the history of our institute, such as Professor Junichi Nishizawa's three elements of optical communication and Professor Shunichi Iwasaki's perpendicular magnetic recording. They started related basic researches at RIEC, which opened new fields in ICT eventually. A more recent case is spintronics, which Professor Hideo Ohno has led from basic science to application to new devices. Magnetoresistive Random Access Memory (MRAM) is a device that uses the spintronics technology, and is attracting public attention as the promising candidate of a critical and emerging device in the near future ICT. The environment in which Tohoku University and RIEC operate is constantly changing. Recognizing roles of university, RIEC must utilize resources efficiently to execute its mission and develop the environment for the purpose.

Since 2004, the institute's organizational structure has been organized into three units: four research divisions (Information Devices Division, Broadband Engineering Division, Human Information Systems Division, and Systems &

Software Division), two laboratories (Laboratory for Nanoelectronics and Spintronics, and Laboratory for Brainware Systems), and the Research Center for 21st Century Information Technology. These units are engaged in research aimed at achieving fruition over different time scales (Research Divisions: 20 years, Laboratories: 10 years, Research Center: 5 years). In addition, we collaborate closely with Tohoku University's graduate schools in subjects relating to electrical engineering (School of Engineering, Graduate School of Information Sciences, and Graduate School of Biomedical Engineering) in order to cover a wide range of cutting-edge research fields and foster the development of outstanding researchers and engineers.

RIEC has also been certified by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) as a Joint Usage/Research Center for collaborative research in information science and technology. The fiscal year 2021 marked the final year of the program's second term. After the evaluation, RIEC has been certified again in the program's third term by the MEXT. As increase of importance of cooperation across different organizations, our role in advancing the information and communication community—both in Japan and overseas—will become increasingly important. To this end, we are collaborating on joint research projects with external researchers and engineers from industry, government, and academia in a systematic manner.

Today, information and communication technology are an essential part of the social infrastructure. We must therefore realize faster, higher-capacity telecommunications with greater energy efficiency performance, while the experience of the Great East Japan Earthquake of 2011 reemphasized the importance of ensuring that our social infrastructure has a high resilience to disaster. We are expected to contribute to a new paradigm of information processing and communication methods that interconnect people in a fundamentally different way. Developed by RIEC over more than 20 years, Brainware has become increasingly important with current trends in artificial intelligence (AI) research. We will continue to address these social needs by fully leveraging our strengths as a university-affiliated research center. In doing so, we hope to forge the path to a new world of communication, and through these efforts continue to promote education going forward.

To contribute to the improvement of our research activities and support future developments, we publish this Annual Report every year to make our

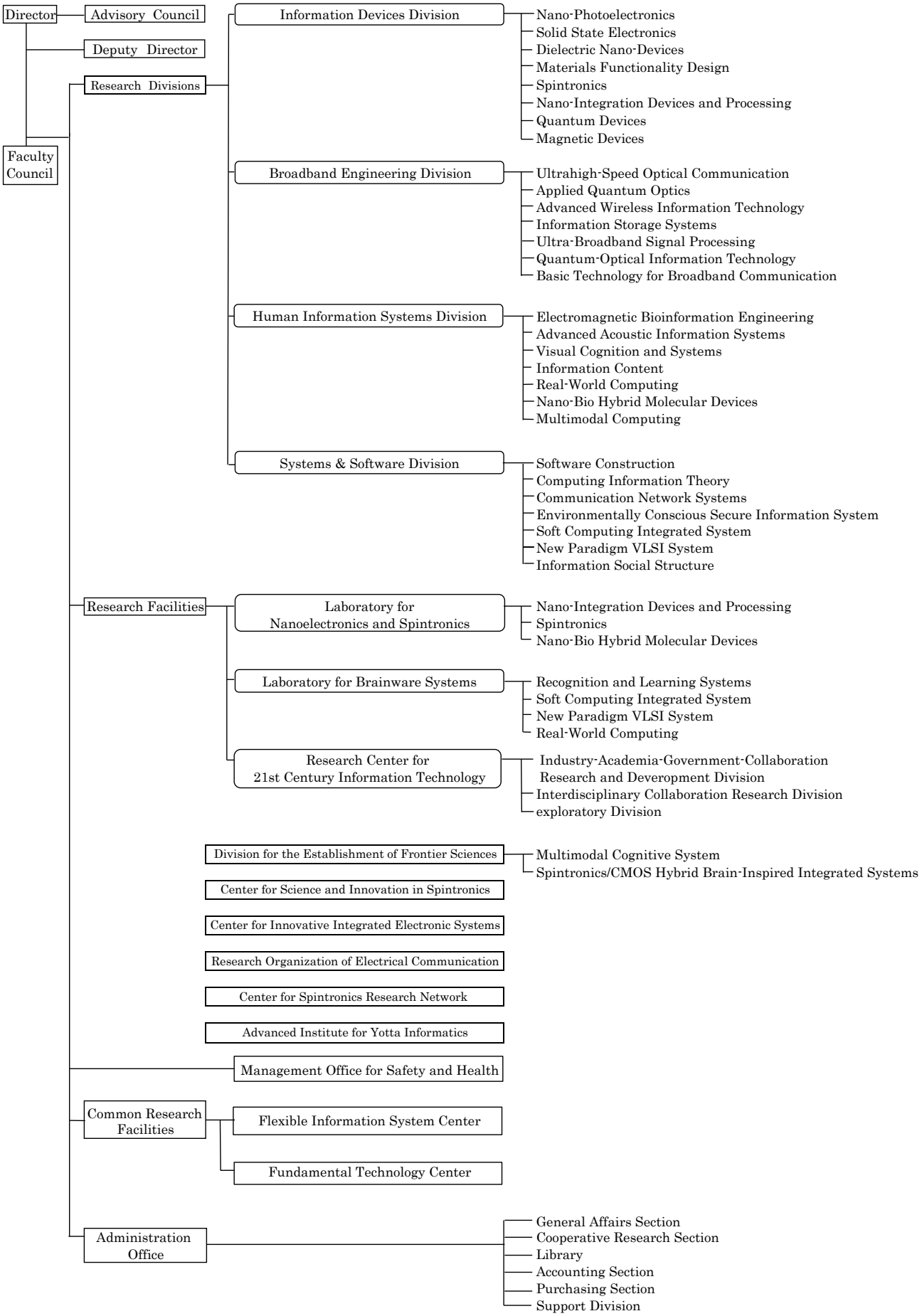
activities relating to research, education, and social contribution widely available for public scrutiny. This edition contains reports on a range of activities, including the research conducted by each of our departments and laboratories, collaborative research projects, international activities, social contributions, the RIEC symposia, activities of the engineering research association, and RIEC lectures. The bibliography section also includes data on the various activities we have conducted over the last five years.

We welcome your frank opinions regarding our activities, and look forward to your continued guidance and support in the future.

May, 2022

Takahiro Hanyu
Director, Research Institute of Electrical Communication

2. Organization Chart



3. Research Activities

Targets and achievements of the Information Devices Division

The main aim of the information devices division is to create advanced nano-information devices utilizing physical phenomena. To accomplish this goal, we conduct research on subjects related to material design, evaluation, process, device, and system. The research developed in this division provides an important basis for achieving the purpose of foundation of this research institute, and we aim to develop completely new functional information devices for next-generation information processing and communication. Thus we study new functionalities employing exotic materials and nanostructures, and apply such functionalities to nanophotoelectronic devices, new dielectrics-based nano-devices for information storage, quantum electronics devices, spintronics devices, and next generation semiconductor devices.

To achieve the goal, the following 8 laboratories are carrying out researches and developments.

1. Nano-Photoelectronics
2. Solid State Electronics
3. Dielectric Nano-Devices
4. Materials Functionality Design
5. Spintronics
6. Nano-Integration Devices and Processing
7. Quantum Devices
8. Magnetic Devices (Visitor Section)

The research target and the summary of activities of each sub-division in FY2021 are described in the following pages.

Nano-Photoelectronics

Exploring optical and electronic properties of nanometer-sized structures

Nano photomolecular electronics Satoshi Katano, Associate Professor

[Research Target and Activities]

The research goal of the nano-photoelectronics laboratory is to elucidate the physical and chemical properties of electronic materials where the light and electrons interacted in the nanometer region. We are also interested in the basic research issues to create new information device materials which are indispensable for the development of advanced optical information communication. By using atomic scale manipulation, we are promoting research to achieve next-generation optoelectronic devices with high functionality and efficiency. To elucidate the photoelectronic properties of a single molecule and nanostructure, we utilize scanning tunneling microscopy (STM) and STM-based spectroscopy. We are also interested in the methods for the fabrication of nanostructures using the molecular deposition and self-assembled monolayer techniques. Theoretical calculations are used complementary to experiments. The summary of our achievements in 2021 is as follows.

(1) Nanoscale photoelectric spectroscopy of graphene oxide

The photoelectron characteristics of graphene oxide (GO) are dominated by nanostructures composed of a conductive sp^2 domain and an insulating sp^3 domain to which oxygen functional groups are connected. Note that the size and spatial distribution of sp^2 domains are the main factors that determine the functionality of GO such as electrical conduction and luminescence. In this research, we conducted research to elucidate the photoelectric properties of GO by means of STM spectroscopy. STS revealed the electronic states localized in GO. The structure and chemical state of the molecular film used as the sample substrate were also evaluated by HREELS.

(2) Evaluations of chemical states of molecular films using density functional theory

First-principles calculation has been used to evaluate the chemical state of the polyvinylpyrrolidone (PVP) polymer thin film. Structural and vibrational energy analysis by the density function theory (DFT) revealed that there is anisotropy in molecule-to-molecule and metal-to-molecule interactions, which are identified by the correlation between these chemical interactions and vibrational energy.

(3) Phase transition-induced structural change of $Ge_2Sb_2Te_5$ surface

Reversible structural change between amorphous and crystalline states by the external stimulus has been reported for chalcogenide semiconductors, such as Ge-Sb-Te (GST) alloys. It is known that such a structural phase transition accompanies with the optical and electrical changes, which can be applicable to the non-volatile memories. In this study, we used microscopy techniques to reveal the nanoscale surface structures of amorphous and crystalline GST. Furthermore, we utilized the electric discharge technique to induce the phase transition.

[Staff]

Associate Professor Satoshi Katano, Dr.

[Profile]

Dr. Satoshi Katano received his D. Sci. degree from Department of Electronic Chemistry, Tokyo Institute of Technology in 2003. He was a postdoctoral research fellow in RIKEN (2003-2006). He joined RIEC, Tohoku University as an assistant Professor in 2006 and was promoted to an associate Professor in 2012. His research interests include surface science and nano-scale molecular optoelectronics.

[Papers]

1. T. Iwahori, A. Mizuno, A. Ono, Y. Uehara, and S. Katano*, "Thermally and photoinduced structural and chemical changes of a silver nanocube array on Au(111)", *RSC Adv.*, **11**, 15847-15855 (2021).
2. S. Morita, J. Sakai, M. Kuwahara, and S. Katano*, "Phase Transition-induced Structural Change of $Ge_2Sb_2Te_5$ Surface", *29th Int. Colloquium on Scanning Probe Microscopy (ICSPM29)*, online, December 9th (2021).
3. S. Katano*, T. Sasajima, and R. Kasama, "Nanoscale Observation of Light Emission from Reduced and Unreduced Graphene Oxide", *29th Int. Colloquium on Scanning Probe Microscopy (ICSPM29)*, online, December 9th (2021).
4. S. Katano*, Illustrated Handbook of Surface Analysis "STM light emission", Asakura shoten, (2021).

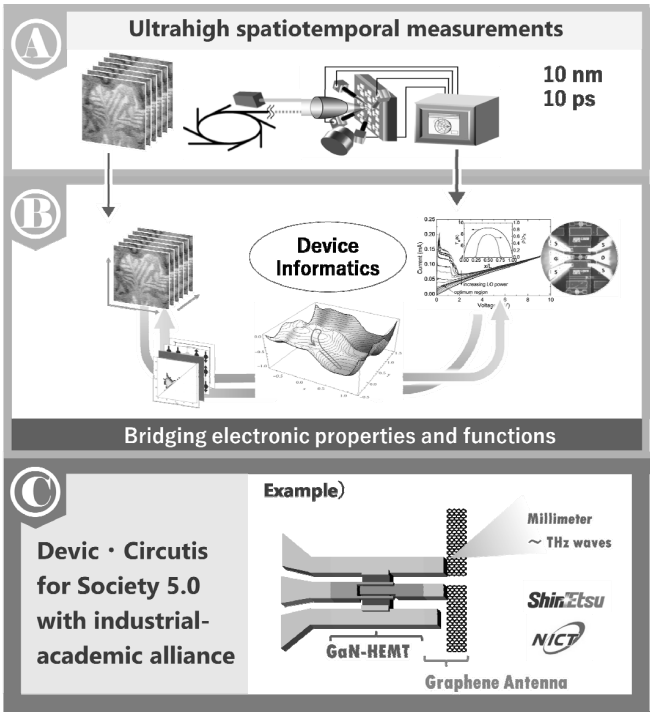
Solid State Electronics Laboratory

Creating Next-generating Devices for contributing Society 5.0 with low environmental load materials

Solid State Physics for Electroncis Hirokazu Fukidome, Associate Professor

[Research Target and Activities]

To accomplish SDGs, Beyond 5G devices, which are the infrastructure of Society 5.0, should be constructed with low environmental load materials. Unfortunately, however, the candidates of Beyond 5G devices consist of rare and toxic elements. To solve this issue, we make efforts to create the Beyond 5G devices by using low environmental load materials with excellent electronic properties, such as graphene and borophene that are 2D materials of carbon and boron.



In FY2021, we tackled in socially implementing a novel method of producing a wafer-scale ultrahigh quality graphene with an affordable cost, down to < 1/10 cost, and graphene transistors operating in THz frequencies. Furthermore, we developed spatiotemporal operando x-ray spectroscopy, enabling spatio-temporally examining electronic states of advanced devices. Finally, we have tried in creating device informatics that bridges electronic properties and functionality of cutting-edge devices.

[Staff]

Associate Professor : Hirokazu Fukidome, Dr.
Technical Assistant : Fuminori Sasaki, Mr.
Technical Assistant : Kumi Namiiri
Technical Assistant : Misako Suzuki

[Profile]

Prof. Hirokazu Fukidome received Ph.D on chemistry from Osaka University. After serving for Bell Labs and RIKEN, he became assistant professor at RIEC in 2008. He has been associate professor at RIEC since 2012. He has been engaged on two-dimensional Dirac electron systems and their operando-microscopy analysis. He was awarded the Best Paper Award from the Surface Science Society of Japan (2011). M. Ishida Research Foundation Award (2015). RIEC Award (2016).

[Papers]

[1] Y. Fukaya, Y. Zhao, H.-W. Kim, J.-R. Ahn, H. Fukidome, and I. Matsuda, “Atomic arrangements of quasicrystal bilayer graphene: Interlayer distance expansion”, Physical Review B, 104 (2022), pp. L180202-1-L180202-5.

[2] Y. Zhao, T. Suzuki, T. Iimori, H.-W. Kim, J.-R. Ahn, M. Horio, Y. Sato, Y. Fukaya, T. Kanai, K. Okazaki, S. Shin, S. Tanaka, F. Komori, H. Fukidome, and I. Matsuda, “Environmental effects on layer-dependent dynamics of Dirac fermions in quasicrystalline bilayer graphene”, Physical Review B, 105 (2022), pp. 115304-1-115304-8.

[3] T. Otsuji, S. A. Boubanga-Tombet, A. Satou, D. Yadav, H. Fukidome, T. Watanabe, T. Suemitsu, A. A. Dubinov, V. V. Popov, W. Knap, V. Kachorovskii, K. Narahara, M. Ryzhii, V. Mitin, M. S. Shur, and V. Ryzhii, “Graphene-based plasmonic metamaterial for terahertz laser transistors”, Nanophotonics, (2022), accepted. Doi: 10.1515/nanoph-2021-0651.

Dielectric Nano-Devices

Research on Dielectric Nano Science and Technology

Dielectric Nano-Devices Yasuo CHO, Professor
Dielectric Nanoscale Measurement Systems Kohei YAMASUE, Associate Professor
Dielectric Materials Science and Engineering Yoshiomi HIRANAGA, Associate Professor

[Research Target and Activities]

Our main area of interest is evaluation and development of dielectric materials, including ferroelectric and piezoelectric materials and their application to communication devices and ferroelectric data storage systems. Our major contributions to advancement in these fields are the invention and the development of "Scanning Nonlinear Dielectric Microscope" (SNDM) which is the first successful purely electrical method for observing the ferroelectric polarization distribution and it has already been put into practical use. The resolution of the microscope has been improved up to atomic scale-order. Therefore, it has a great potential for realizing the ultra-high density ferroelectric recording system. In addition, SNDM can be used for the evaluation of various semiconductor materials and devices.

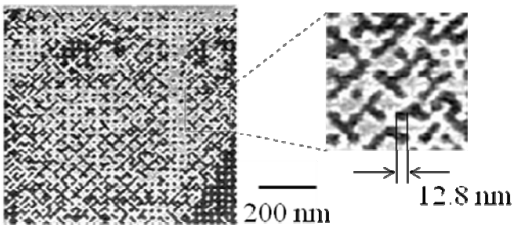


Fig.1 Digital bit data written on ferroelectric single crystal with the areal recording density of 4 Tbit/inch^2.

Major achievements of studies in 2021 are as follows: (1) A high-precision C-V mapping method useful for revealing local ferroelectric polarization switching dynamics was developed based on a new digitizer-based SNDM and post-signal analysis such as primary component analysis (2) Simultaneous local DLTS and CV profiling methods by time-resolved SNDM were demonstrated for the evaluation of semiconductor insulator interfaces including SiO_2/Si and SiO_2/SiC interfaces (3) We developed a theory for a novel boxcar averaging SNDM improving the S/N ratios of SNDM in a peak-force tapping mode.

[Staff]

Professor : Yasuo Cho, Ph.D. Associate Professor : Kohei Yamasue, Ph. D.
Associate Professor: Yoshiomi Hiranaga, Ph.D.

[Profile]

Yasuo Cho graduated in 1980 from Tohoku University in electrical engineering department. In 1985 he became a research associate at Research Institute of Electrical Communication, Tohoku University. In 1990, he received an associate professorship from Yamaguchi University. He then became an associate professor in 1997 and a full professor in 2001 at Research Institute of Electrical Communication Tohoku University. During this time, his main research interests included nonlinear phenomena in ferroelectric materials and their applications, research on the scanning nonlinear dielectric microscope, and research on using the nonlinear dielectric microscope in next-generation ultrahigh density ferroelectric data storage (SNDM ferroelectric probe memory).

Kohei Yamasue received the Ph. D degree in engineering from Kyoto University in 2007. He then became a postdoctoral fellow in 2007 and an assistant professor in 2008 at Venture Business Laboratory, Kyoto University. In 2010, he joined Research Institute of Electrical Communication, Tohoku University, as an assistant professor and, in 2016, became an associate professor. His main interests include the development of atomic resolution scanning nonlinear dielectric potentiometry and its applications to the evaluation of the next-generation electronic materials and devices.

Yoshiomi Hiranaga received the Ph. D degree in engineering from Tohoku University in 2006. He then became a research associate in 2006 (2007- assistant professor) at Research Institute of Electrical Communication, Tohoku University, and became an associate professor in 2020. His main interests include domain switching phenomena on ferroelectric materials in the nanoscale area and their applications for next-generation high-density data storage devices.

[Papers]

[1] Y. Hiranaga, T. Mimura, T. Shimizu, H. Funakubo and Y. Cho, Jpn. J. Appl. Phys, Vol. 60, SFFB09, 2021
[2] K. Yamasue and Y. Cho, Microelectron. Reliab., Vol. 126, 114284, 2021
[3] K. Yamasue and Y. Cho, Nanomaterials, Vol. 12, No. 5, 794, 2022

Materials Functionality Design

Computational Design of Functional Materials for Information Devices

Materials Functionality Design: Masafumi Shirai, Professor
Materials Science under Extreme Conditions: Kazutaka Abe, Associate Professor

[Research Target and Activities]

Our research targets are as follows: (1) theoretical analyses of quantum phenomena in materials for advanced information devices, (2) computational design of new materials possessing novel functionalities for improvement of device performance, and (3) development of new design procedures based on large-scale computational simulation and data-driven approaches.
Our research activities in FY 2021 are as follows:

(1) Ferromagnetism and giant magnetoresistance in FeAs/InAs superlattices

InAs is a semiconductor used in high-speed transistors and long-wavelength optical devices. We have investigated the structural and magnetic properties of FeAs/InAs superlattices using the first-principles calculations with the experimental group in The University of Tokyo. As a result, we have revealed that the high Curie temperature and large magnetoresistance up to 500%. Moreover, the magnetoresistance can be tunable by a gate voltage. Thus, FeAs/InAs superlattices are promising materials for spintronics applications [1].

(2) Data-driven materials exploration combining first-principles calculation and machine learning

We explored highly spin-polarized materials for application to the electrodes of magnetic tunnel junctions to improve the magnetoresistance at room temperature. As a result, we found new Heusler alloys IrCrMnAl and IrCrMnGa, which are promising candidates as electrode materials of MgO-based magnetic tunnel junctions [2].

(3) Hydrides at high pressures

A new hydrocarbon compound, which consists of two-dimensional CH planes and is insulating, is predicted by using *ab initio* methods. Unlike the graphene-like phases so far predicted, the new CH phase has a diamond-like structure. The diamond-like CH is stabilized thermodynamically above about 10 GPa. Yet, the structure is dynamically stable at much lower pressures and possibly exists as a metastable phase even at one atmosphere.

[Staff]

Professor: Masafumi Shirai, Dr.
Associate Professor: Kazutaka Abe, Dr.
Assistant Professor: Masahito Tsujikawa, Dr.
Assistant Professor: Hikari Shinya, Dr.

[Profile]

Masafumi Shirai received the Doctor of Engineering degree from Osaka University in 1989. Since 2002, he has been a Professor at Tohoku University.
Kazutaka Abe received Doctor of Science degree from Osaka University in 1998. Since 2003, he has been at Tohoku University as a Research Associate and currently as an Associate Professor.

[Papers]

[1] L. D. Anh, T. Hayakawa, Y. Nakagawa, H. Shinya, T. Fukushima, M. Kobayashi, H. Katayama-Yoshida, Y. Iwasa, and M. Tanaka, "Ferromagnetism and giant magnetoresistance in zinc-blende FeAs monolayers embedded in semiconductor structures," Nat. Commun., Vol. 12, No. 4201, pp. 1-10, 2021

[2] T. Roy, M. Tsujikawa, and M. Shirai, "IrCrMnZ (Z = Al, Ga, Si, Ge) Heusler alloys as electrode materials for MgO-based magnetic tunnel junctions: A first-principles study," J. Phys. D: Appl. Phys., Vol. 55, Article no. 125303, pp. 1-12, 2022

[3] K. Abe, "Metallic silicon subhydrides at high pressures studied by *ab initio* calculations," Phys. Rev. B, Vol. 103, Article no. 134118, pp. 1-7, 2021

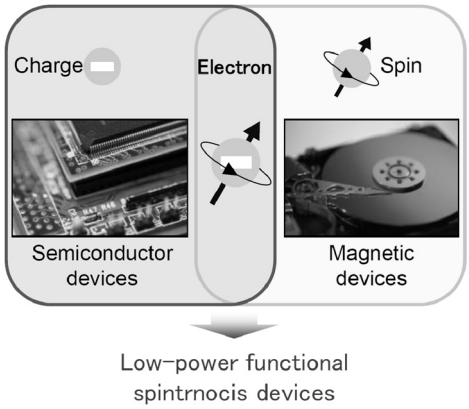
Spintronics

Advanced technology for spintronics-based devices

Nano-Spin Materials and Devices: Shunsuke Fukami, Professor

[Research Target and Activities]

We aim to deepen the understanding of spin-related physics and to develop new functional materials and devices in which electron and its spin states are controlled. We are also working on research and development of advanced technology for spintronics-based devices and unconventional computing, which offer high-performance and low-power information and communication technologies.
The outcomes in the last fiscal year include (1) development of artificial neuron and synapse devices using an antiferromagnet/ ferromagnet structure, (2) demonstration of probabilistic computing using developed unconventional spintronics devices, and (3) realization of synthetic antiferromagnetic skyrmions allowing current-induced motion without skyrmion Hall effect.



[Staff]

Professor: Shunsuke Fukami, Ph. D.
Assistant Professor: Shun Kanai, Ph. D. , Justin Llandro, Ph. D.

[Profile]

Shunsuke Fukami received Ph. D. degree from Nagoya University in 2012. He joined NEC Corp (2005). He moved to Tohoku University as an Assistant Professor (2011) and then as an Associate Professor (2015). He received the JSAP Paper Award (2012), the RIEC Award for Tohoku University Researchers (2013), the Funai Research Incentive Award (2014), the JSAP Young Scientist Presentation Award (2014), the Young Scientists' Prize of Science and Technology by the MEXT (2015), the Harada Young Research Award (2015), DPS Paper Award (2016), ImPACT Symposium – Best Poster Award (2017), Aoba Foundation Award (2017), Asian Union of Magnetics Societies, Young Researchers Award (2018), the Outstanding Research Award of the Magnetics Society of Japan (2018), Gold Prize of Tanaka Kikinzoku Memorial Foundation (2019), the JSAP Outstanding Paper Award (2019), Marubun Research Encouragement Award (2021), and InaRIS Research Fellow (2022).

[Papers]

[1] G. Wolfowicz, F. J. Heremans, C. P. Anderson, S. Kanai, H. Seo, A. Gali, G. Galli, and D. D. Awschalom, "Quantum guidelines for solid-state spin defects," Nature Reviews Materials **6**, 906-925 (2021).
[2] Y. Takeuchi, Y. Yamane, J. Yoon, R. Itoh, B. Jinnai, S. Kanai, J. Ieda, S. Fukami, and H. Ohno, "Chiral-spin rotation of non-collinear antiferromagnet by spin–orbit torque," Nature Materials **20**, 1364-1370 (2021).
[3] B. Jinnai, J. Igarashi, T. Shinoda, K. Watanabe, S. Fukami, and H. Ohno, "Fast Switching Down to 3.5 ns in Sub-5-nm Magnetic Tunnel Junctions Achieved by Engineering Relaxation Time," 67th Annual IEEE International Electron Devices Meeting (IEDM2021), pp. 2.6.1-2.6.4 (2021).

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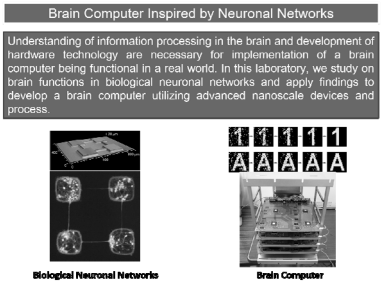
Nano-Integration Devices and Processing

Deepening of nano-integration technology and development of brain computer

Nano-Integration Devices — Shigeo Sato, Professor
Group IV Quantum Heterointegration — Masao Sakuraba, Associate Professor
Nano-Integration Neurocomputing Systems — Hideaki Yamamoto, Associate Professor

[Research Target and Activities]

In this laboratory, we focus on non-von Neumann computing, such as brain computing and quantum computing, and study their hardware technology. We conduct research on various topics including device, process, circuit, algorithm, and neuroscience, and build revolutionary new computer technology by integrating our findings. In this year, following results have been obtained: (1) Toward the development of neuromorphic computation hardware, we fabricated a recurrent neural network LSI composed of spiking neurons that can reproduce various neuron pulses with ultra-low power consumption. We confirmed by electrical measurements that our analog MOS circuit correctly operated in the weak inversion region and that the network showed various responses depending on input signal. (2) Low-energy plasma chemical vapor deposition method enables the formation of Si nitride film with a composition close to stoichiometric ratio, and it is experimentally shown that a nanometer-thick Si nitride film under the thermally oxidized SiO2 dielectric film can suppress thermal oxidation of the substrate surface. (3) Toward the development of a dedicated hardware for reinforcement learning, we investigated the relationship between the bit-length of floating-point operations and the learning performance of the Q-learning algorithm.



Towards the Realization of a Brain Computer

[Staff]

Professor : Shigeo Sato, Dr.
Associate Professor : Masao Sakuraba, Dr.
Associate Professor : Hideaki Yamamoto, Dr.
Research Fellow: Satoshi Moriya, Dr.

[Profile]

Shigeo Sato was received his B.E. and Ph.D. degrees from Tohoku University, in 1989 and 1994, respectively. In 1996, he joined the Research Institute of Electrical Communication, Tohoku University. Now, he studies brain computer and quantum computer as a professor.

Masao Sakuraba received his B.E. and Ph.D. degrees from Tohoku University in 1990 and 1995, respectively. In 1995, he joined the Research Institute of Electrical Communication, Tohoku University. Now, he studies group IV quantum heterointegration as an associate professor.

Hideaki Yamamoto received his B.E. and Ph.D. degrees from Waseda University in 2005 and 2009, respectively. In 2020, he joined the Research Institute of Electrical Communication, Tohoku University. Now, he studies neuronal network functions as an associate professor.

[Papers]

[1] S. Sato, S. Moriya, Y. Kanke, H. Yamamoto, Y. Horio, Y. Yuminaka, J. Madrenas, “A subthreshold spiking neuron circuit based on the Izhikevich model”, Lecture Notes in Computer Science (ICANN 2021), 12895, 177-181 (2021).

Quantum Devices

Electronic properties of nanostructures and device applications

Quantum Devices: Tomohiro Otsuka, Associate Professor

[Research Target and Activities]

In solid-state nanostructures, exotic phenomena like quantum effects occur. We are exploring interesting properties of solid-state nanostructures utilizing precise and high-speed electric measurement and control techniques. We are also developing materials and devices using nanostructures.

Our research activities in FY 2021 are the following.

(1) Development of local measurement and control techniques

We developed electronic measurement and control methods of local electronic states in nanostructures utilizing semiconductor quantum dots. We improved the methods with high-frequency techniques and data informatics approaches.

(2) Measurement of local electronic states in nanostructures

We measured local electronic and spin states in nanostructures utilizing sensitive electronic measurement techniques. We revealed the detail of local electronic states in quantum dot devices and new materials [3].

(3) Development of quantum devices and systems

We studied semiconductor quantum bits for future quantum information processing. We worked on quantum bit operations and readout and developed techniques for scale-up of quantum systems [1, 2].

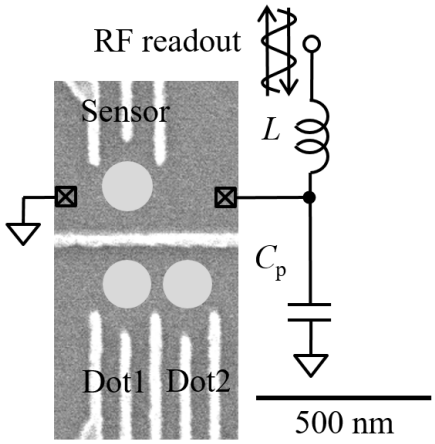


Figure: Scanning electron micrograph of a nanostructure device

[Staff]

Associate Professor: Tomohiro Otsuka, Ph. D.

[Profile]

Tomohiro Otsuka received Ph. D. degree from the University of Tokyo in 2010. After working for the University of Tokyo and RIKEN, he became an Associate Professor at Tohoku University in 2018. He received Research Encouraging Prize from School of Science, University of Tokyo (2010), Young Scientist Award of the Physical Society of Japan (2017), RIKEN Researcher Incentive Award (2017), Yazaki Memorial Foundation for Science and Technology Research Encouraging Award (2018), and the Young Scientists' Prize of Science and Technology by MEXT (2018), Distinguished Researcher in Tohoku University (2020).

[Papers]

[1] Y. Kojima, T. Nakajima, A. Noiri, J. Yoneda, T. Otsuka, K. Takeda, S. Li, S. D. Bartlett, A. Ludwig, A. D. Wieck, and S. Tarucha, "Probabilistic teleportation of a quantum dot spin qubit", npj Quantum Information 7, 68 (2021).

[2] T. Otsuka, M. Shinozaki, Y. Muto, T. Kitada, T. Nakajima, M. R. Delbecq, J. Yoneda, K. Takeda, A. Noiri, T. Ito, A. Ludwig, A. D. Wieck, and S. Tarucha, "Noise analysis of radio-frequency reflectometry for single spin and charge detection in quantum dots", 1st Online RIEC International Workshop on Spintronics, Online, Nov. 18, 2021.

[3] T. Abe, T. Kitada, N. Ito, T. Tanaka, K. Nakahara, and T. Otsuka, "Quantum dots formed in GaN/AlGaN FETs and channel length dependence", International Conference on Electronic Properties of Two-Dimensional Systems, Online, Nov. 2, 2021.

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Broadband Engineering Division: Research Targets and Results

In order to establish future broadband communication systems and novel devices that can be flexibly applied to future ubiquitous ultra-high capacity information communications, research and development is being carried out over the wide spectrum of microwaves, millimeter/submillimeter waves, terahertz waves, and lightwaves with regard to information generation, transmission, processing, and storage technologies.

(1) Ultrahigh-Speed Optical Communication

We are engaged in research on ultrahigh-speed optical transmission, digital coherent transmission, and high-speed and spectrally efficient optical transmission by combining these two approaches. With a view to supporting innovative new ICT services such as 5G and IoT, our goal is also to develop novel transmission schemes integrating optical and wireless communications.

This year, we successfully achieved a 8 ch WDM transmission of 1.28 Tbit/s Nyquist pulses with a total capacity of 10.2 Tbit/s over 2100 km, which is the longest transmission distance at > 1 Tbit/s/ch. We also demonstrated 64 Gbit/s, 256 QAM coherently-linked optical and wireless transmission, where the 64 Gbit/s data were seamlessly transmitted over 10 km through an optical fiber and 40 m wirelessly in the 60 GHz band.

(2) Applied Quantum Optics

Novel functional semiconductor photonic devices including photonic integrated circuits are being investigated to explore next-generation photonic network systems.

A study on ultra-high-speed semiconductor laser introducing hybrid modulation scheme was being continued. It was confirmed numerically that the modulation bandwidth of the hybrid modulation semiconductor laser source we proposed can be enlarged up to 130 GHz by shortening its cavity length to 150 μm. It was also confirmed that the short cavity hybrid modulation semiconductor laser can operate by 100 Gbit/s NRZ signal under dynamic-single-mode condition. Furthermore, the study on compact and narrow linewidth semiconductor laser sources was also being proceeded by applying the optical negative feedback technology we proposed. It was confirmed experimentally that high SNR FMCW LiDAR system with more than 30dB SNR beat spectra even for 450 m distance measurement can be realized by applying the compact optical negative feedback laser.

(3) Advanced Wireless Information Technology

We are actively engaged in research work on wireless Internet of Things (IoT) technologies for next-generation wireless systems, which include terrestrial / satellite communications. The covered areas of us are all technical fields from the lower to higher layers, i.e., digital signal processing, RF/Mixed-signal device, antenna, transceiver, and subsystem technologies. This year, we have successfully developed a 20GHz-Band optical-fiber-feed 1-bit band-pass delta-sigma direct digital RF transmitter using first image component of QSFP28 module output. We also developed gain enhanced 130GHz-band CMOS amplifiers by employing a novel positive feedback circuit and low loss matching circuits for sub-THz short-range wireless communication system.

(4) Information Storage Systems

Research on next-generation perpendicular magnetic recording is being carried out to meet the strong demand for high density, high performance storage due to the rapid growth of the internet and web services. To establish high performance data-intensive analytics, a computational storage analytics platform with unified computing and storage is targeted in the research and development.

We have been investigating novel, three-dimensional, energy-assisted recording technologies that enable selective recording on media with multiple, discrete recording layers. The optimal conditions for heat assisted magnetic recording (HAMR) using near-field light to heat nanometer-sized areas of a medium have been identified. The feasibility of realizing the technology that enables a doubling of the data storage capacity has been confirmed. We have constructed a “computational storage system” with unified PB-class storage and computation functions, and integrated the object distributed storage Ceph. The data access performance for the real application of three-dimensional visualization of neurons imaged by fluorescent microscopy has been confirmed.

(5) Ultra-Broadband Signal Processing

We are developing novel, integrated electron devices and circuit systems operating in the terahertz region. One of our major concerns is a new material called “graphene”, a single-layered honeycomb-lattice carbon crystal.

First, towards the creation of novel current-injection graphene THz lasers, we developed a graphene laser-transistor featured with our original asymmetric dual-grating gates demonstrating coherent amplification of THz radiation with the maximal gain of 9% at room temperature promoted by graphene plasmon instabilities driven by dc-channel current flow (Press-released on July 2020). Second, regarding the InGaAs-channel plasmonic THz detector, we demonstrated that the "3D rectification effect", where the diode current nonlinearity associated with the electron tunneling is superimposed onto the plasmonic hydrodynamic nonlinearities, can take place by applying a positive gate bias voltage in the gate-readout configuration of the photovoltage and succeeded in drastic enhancement of the detector responsivity by one order of magnitude.

(6) Quantum-Optical Information Technology

Our goal is to develop quantum information devices utilizing the quantum interaction between photons and electrons in solids.

In 2021, we have achieved (1) nonlocal generalized quantum measurements of bipartite spin products using entangled meter, (2) generation of spectrally factorable photon pairs via multi-order quasi-phase-matched spontaneous parametric downconversion, and (3) plasmon-enhanced single photon source directly coupled to an optical nanofiber.

Research Laboratory of Ultrahigh-Speed Optical Communication

Toward Innovative Optical Transmission from Backbone to Access Networks

Research Area of Ultrahigh-Speed Optical Transmission Toshihiko Hirooka, Professor
Research Area of Lightwave Control System Keisuke Kasai, Associate Professor

[Research Target and Activities]

Advanced global ICT services such as ultrahigh-definition video transmission and ultra-realistic communication cannot be realized without high-speed and large-capacity optical transmission systems. At the same time, optical transmission schemes with high spectral efficiency are crucial in terms of the maximum utilization of limited bandwidth resources. In our laboratory, we are engaged in research on ultrahigh-speed optical transmission using optical time division multiplexing with a single-channel Tbit/s-class capacity, digital coherent QAM optical transmission, and high-speed and spectrally efficient optical transmission by combining these two approaches. With a view to supporting innovative new ICT services such as 5G and IoT, our goal is also to apply digital coherent transmission to access networks and mobile fronthaul, and to develop novel transmission schemes integrating optical and wireless communications. This year, we successfully achieved a 8 ch WDM transmission of 1.28 Tbit/s Nyquist pulses with a total capacity of 10.2 Tbit/s over 2100 km by optimizing the roll-off factor, which is the longest transmission distance at > 1 Tbit/s/ch (Fig. 1). We also demonstrated 64 Gbit/s, 256 QAM coherently-linked optical and wireless transmission for next-generation RAN. 64 Gbit/s data were seamlessly transmitted over 10 km through an optical fiber and 40 m wirelessly in the 60 GHz band.

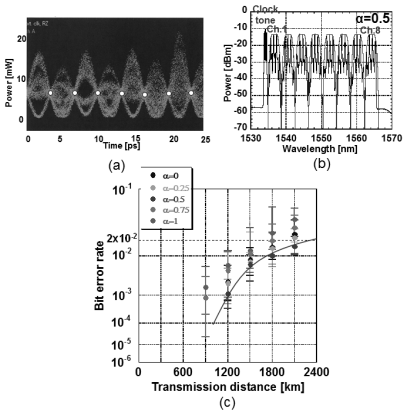


Fig. 1. 10.2 Tbit/s (1.28 Tbit/s x 8 ch) WDM Nyquist pulse transmission over 2100 km.

[Staff]

Professor: Toshihiko Hirooka, Dr. Associate Professor: Keisuke Kasai, Dr.

[Profile]

Toshihiko Hirooka received the Ph. D. degree from Osaka University in 2000. From 2000 to 2002, he was a Research Associate at University of Colorado at Boulder. He is currently a Professor at the Research Institute of Electrical Communication, Tohoku University. He has been engaged in research on ultrahigh-speed optical communications and nonlinear fiber optics.

Keisuke Kasai received the Ph. D. degree from Tohoku University in 2008. From 2009 to 2012, he was a JSPS Research Fellow. He is currently an Associate Professor at the Research Institute of Electrical Communication, Tohoku University. He has been engaged in research on lightwave control techniques and coherent optical communications.

[Papers]

[1] K. Kasai, T. Sato, T. Hirooka, M. Yoshida, and M. Nakazawa, "64 Gbit/s, 256 QAM Transmission Through Coherent Optical-Wireless Link at 61 GHz Using Simple and High OSNR Carrier Frequency Converter," OFC 2021, Tu6E.2, June (2021).
[2] A. Watanabe, M. Yoshida, T. Hirooka, and M. Nakazawa, “Single-Channel 1.28 Tbit/s Optical Nyquist Pulse Transmission over 3000 km with Roll-off Factor Optimization,” OECC 2021, T4B.6.
[3] K. Kasai, T. Sato, K. Shirahata, T. Hirooka, M. Yoshida, M. Nakazawa, “Performance comparison between injection-locked carrier frequency conversion and self-heterodyne detection methods in coherently-linked optical and wireless transmission for 6G,” ICETC 2021, B1-3.

Applied Quantum Optics

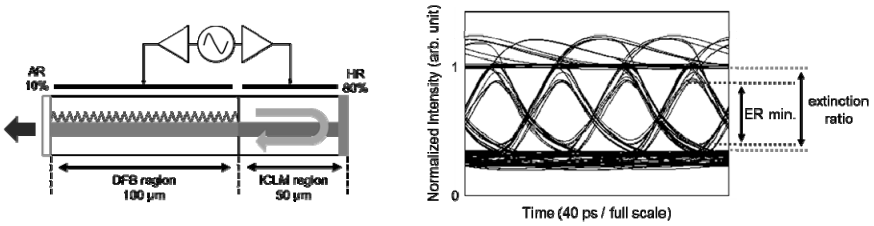
Research on Innovative Highly Functional Photonic Semiconductor Devices

Highly Functional Photonics **Hiroshi Yasaka, Professor**
High accuracy optical measurement **Masato Yoshida, Associate Professor**

[Research Target and Activities]

Novel functional photonic devices including high function laser diode (LD) sources are being investigated to explore new-generation photonic network systems.

The study on ultra-high-speed semiconductor lasers is being continued. It was confirmed numerically that the hybrid modulation semiconductor laser source we proposed can operate 100 Gbit/s NRZ signal under dynamic single-mode condition by shortening its cavity length and widening its modulation bandwidth. Furthermore high SNR FMCW LiDAR system is realized by applying compact and narrow linewidth optical negative feedback semiconductor laser sources we proposed.



Schematic structure of short cavity hybrid modulation laser (left) and its 100 Gbit/s eye pattern under dynamic single mode operation (right).

[Staff]

Professor : Hiroshi Yasaka, Dr.
Associate Professor : Masato Yoshida, Dr.
Assistant Professor : Nobuhide Yokota, Dr.

[Profile]

Hiroshi Yasaka received M.S. degrees in physics from Kyusyu University in 1985, and Ph.D. degree in electronic engineering from Hokkaido University in 1993. In 1985 he joined Nippon Telegraph and Telephone (NTT) Corporation. Since then, he has been engaging in research and development on semiconductor photonic devices for optical fiber communication systems. From 2008 he has been a professor of Tohoku University.

Masato Yoshida received Ph.D. degree in electronic engineering from Tohoku University in 2001. In 2001, he joined the Research Institute of Electrical Communication, Tohoku University. He is currently an Associate Professor of the Institute. He has been engaging in research on fiber lasers and their application to optical measurements.

[Papers]

[1] N. Yokota, H. Kiuchi, and H. Yasaka, "Low-phase-noise optical negative feedback laser for long-distance ranging with high signal-to-noise ratio," 27th International Semiconductor Laser Conference (ISLC), WA1.3, 2020.
[2] N. Yokota, H. Kiuchi, and H. Yasaka, "Directly modulated optical negative feedback lasers for long-range FMCW LiDAR," Optics Express, vol. 30, No. 7, pp. 11693-11703, 2022. (published 23 Mar 2022) / DOI 10.1364/OE.452284
[3] N. Yokota and H. Yasaka, "Spin Laser Local Oscillators for Homodyne Detection in Coherent Optical Communications," Micromachines 12, 573 2021. (May, 18, 2021) / doi.org/10.3390/mi12050573

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Advanced Wireless Information Technology

For realization of the next generation mobile network

Advanced Wireless Information Technology Noriharu Suematsu, Professor

[Research Target and Activities]

We are actively engaged in research work on wireless Internet of Things (IoT) technologies for next generation wireless systems, which include terrestrial / satellite communications. The covered areas of us are all technical fields from the lower to higher layers, i.e., digital signal processing, RF/Mixed-signal device, antenna, transceiver, and subsystem technologies.

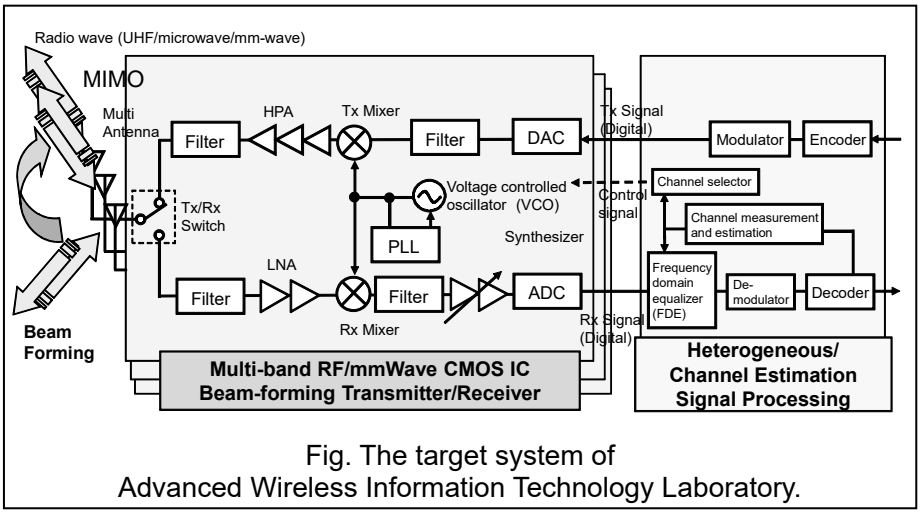


Fig. The target system of
Advanced Wireless Information Technology Laboratory.

This year, we have successfully developed a 60GHz sample and hold (S/H) IC for direct RF underfsampling receiver and a 20GHz-Band optical-fiber-feed 1-bit band-pass delta-sigma direct digital RF transmitter using first image component of QSFP28 module output. We also developed gain enhanced 130GHz-band CMOS amplifiers by employing a novel positive feedback circuit and low loss matching circuits for sub-THz short-range wireless communication system. We received APMC2021 Prize which is the best paper award in Asia Pacific Microwave Conference (one of the top 3 international conference in microwave society.)

[Staff]

Professor: Noriharu Suematsu, Ph. D
Research Fellow: Jean Temga, Ph.D

[Profile]

Noriharu Suematsu received the M.S. and Ph.D. degrees in Electronics and Communication Engineering from Waseda University in 1987 and 2000. From 1987 to 2010, he had been with the R&D center of Mitsubishi Electric, Japan. Since 2010, he has been a professor of Research Institute of Electrical Communication (RIEC), Tohoku University. He received the OHM technology award from the promotion foundation for electrical science and engineering in 2002 and Prize for Science and Technology, the Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology in 2009.He is a fellow of IEICE

[Papers]

[1] J. Zhang, M. Kazuno, M. Motoyoshi, S. Kameda, N. Suematsu, "Image Enhancement in 26GHz-Band 1-Bit Direct Digital RF Transmitter Using Manchester Coding," IEICE Transactions on Communications, Vol. E104.B, No. 6, pp. 654-663, Jun. 2021.

[2] T. Machii, M. Motoyoshi, S. Kameda, N. Suematsu, "Gain Boosted D-Band CMOS Amplifier Using a Radial Stab for Source AC Grounding," 2021 IEEE Asia Pacific Microwave Conference (APMC), pp.190-192, Nov.2021.

[3] T. Chida, S. Kameda, N. Suematsu, "Fundamental Investigation of Backoff Control Method for Fair Communication Opportunity of mmW WBAN in Overcrowded Environment," 13th Asia Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA), vol. 120, no. 405, pp. 1953-1957, Dec. 2021.

[4] T. Furuichi, N. Yoshino, M. Motoyoshi, S. Kameda, N. Suematsu, "A 60 GHz-band S/H CMOS IC for Direct RF Undersampling Receiver," 2022 IEEE Radio and Wireless Symposium (RWS), Jan. 2022.

Information Storage System Laboratory

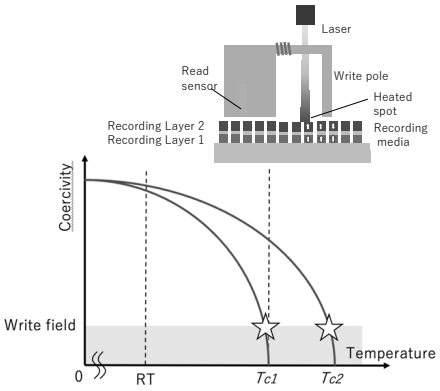
High Density and High Speed Energy Assisted Magnetic Recording, and Computational Storage System Research

Information Storage・Computing Systems, Yoichiro Tanaka, Professor
Recording Theory Computation, Simon Greaves, Associate Professor

[Research Target and Activities]

Research on next-generation perpendicular magnetic recording is being carried out to meet the strong demand for high density, high performance storage due to the rapid growth of the Internet and web services. We use computer simulations to study recording systems and novel technologies to realize high speed, high density data storage. To achieve high performance data-intensive analytics, an intelligent computational storage platform is targeted.

We investigate novel, three-dimensional, energy-assisted recording technologies that enable selective recording on media with multiple, discrete recording layers. In this year, research was concentrated on heat-assisted magnetic recording (HAMR), with the aim of doubling the storage capacity. A HAMR system has shown the potential to record data on media with different Curie temperatures [1][2]. We have constructed 2PB computational storage system for visualization analytics of brain neuro structures. Object based distributed storage Ceph has been integrated in unified computational storage nodes that enabled the fast three-dimensional visualization of neuron structures captured by fluorescent microscopy.



Double-layer HAMR Structure

[Staff]

Professor: Yoichiro Tanaka, Ph.D.
Associate Professor: Simon Greaves, Ph.D.

[Profile]

Yoichiro Tanaka received his BE, MS, and Ph.D. from Tohoku University in 1981, 1983, and 2006, respectively. He joined Toshiba Corporation in 1983. He has been at RIEC, Tohoku University since 2019. His research focus has been on high density perpendicular magnetic recording and information storage systems. He received the Japan Magnetic Society Achievement Award (2006) and Okochi Memorial Prize (2007). He is a fellow of the Japan Magnetic Society.

Simon Greaves has been at Tohoku University since 2003. He developed micromagnetic simulation software to model magnetic recording and to investigate the potential of magnetic, information storage devices. He received his Ph.D. in 1993 from Salford University, UK.

[Papers]

[1] H. Yamane, S. Greaves, Y. Tanaka, "Heat-Assisted Magnetic Recording on Dual Structure Bit Patterned Media", IEEE Trans. Mag. Vol. 57, No.2, pp.1-6, 2021
[2] H. Yamane, S. Greaves, Y. Tanaka, "Optimising the Thickness and Diameter of Dual Structure Patterned Media Dots for Heat Assisted Magnetic Recording", MMM-Intermag 2022, IPA-04, 2022
[3] Yoichiro TANAKA, In-Storage/Memory Computing Platform for Brain Neuro Science, FY 2021 RIEC Annual Meeting on Cooperative Research Projects "Compass for Next-Gen ICT" Program, 2022
[4] Yoichiro Tanaka, Data Storage Consideration in Brain Inspired Computing, Joint Seminar "Brain Inspired Computing; Physics, Architecture, Materials, Applications (BICPAMA)", C-2, December 2021

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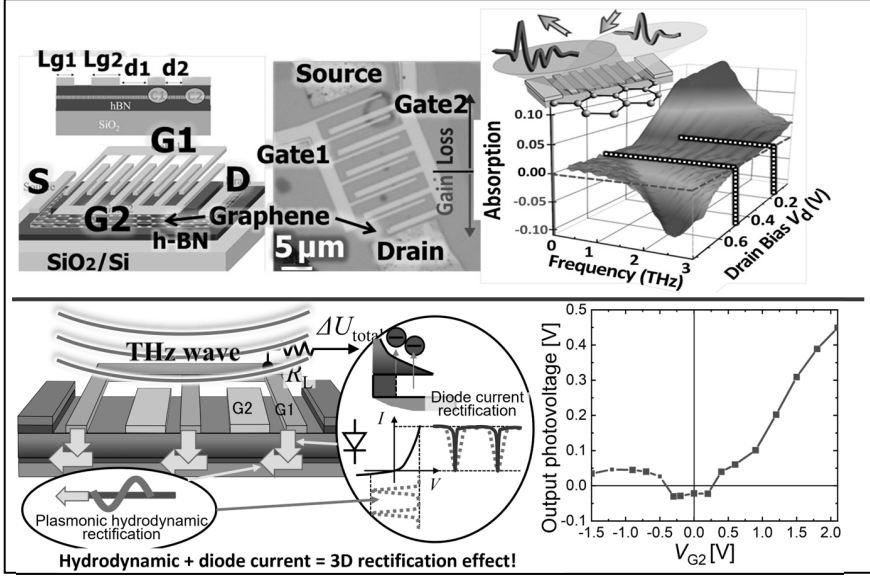
Ultra-broadband Signal Processing

Novel Millimeter-wave and Terahertz Integrated Electron Devices and Systems

Ultra-Broadband Devices and Systems: Taiichi OTSUJI, Professor
Ultra-Broadband Device Physics: Akira SATOU, Associate Professor

[Research Target and Activities]



Top: Schematic and SEM images of an asymmetric dual-grating gate graphene-channel FET and extinction/gain spectra measured at room temperature demonstrating coherent amplification of THz radiation with a gain of up to 9% (negative value for gain).

Bottom: Schematic view of the 3D rectification effect in the InGaAs-based plasmonic THz detector (left) and a cross-sectional structural drawing and experimental result of photovoltage enhancement by the positive gate bias voltage application on THz-pulse detection measurement at 0.8 THz (right).

We are developing novel, integrated electron devices and circuit systems operating in the terahertz (THz) region. First, towards the creation of novel current-injection graphene THz laser-transistors, we developed a graphene laser-transistor featured with our original asymmetric dual-grating gates demonstrating coherent amplification of THz radiation with the maximal gain of 9% at room temperature promoted by graphene plasmon instabilities driven by dc-channel current flow (Press-released on July 2020). Second, regarding the InGaAs-channel plasmonic THz detector, we demonstrated that the "3D rectification effect", where the diode current nonlinearity associated with the electron tunneling is superimposed onto the plasmonic hydrodynamic nonlinearities, can take place by applying a positive gate bias voltage in the gate-readout configuration of the photovoltage and succeeded in drastic enhancement of the detector responsivity by one order of magnitude.

[Staff]

Professor: Taiichi OTSUJI, Dr. Eng.
Associate Professor: Akira SATOU, Dr. Comp. Sci.
Assistant Professor: Takayuki WATANABE, Dr. Eng.
Research Fellow: Victor RYZHII, Ph.D., Chao TANG, Ph.D.
Secretary: Kayo UENO

[Profile]

Taiichi OTSUJI: received the Dr. Eng. deg. from Tokyo Tech., Japan, in 1994. After working for NTT Labs., Japan, since 1984, he joined Kyutech in 1999, as an Assoc. Prof., being a prof. from 2002. Since 2005, he has been a Prof. at RIEC, Tohoku Univ., Japan. Recipient of the 2019 Prizes for Science and Technology, the Commendation for Science and Technology, MEXT, Japan. A Distinguished Lecturer, Electron Device Society, IEEE. A member of IEEE (Fellow), OSA (Fellow), JSAP (Fellow), IEICE (Senior), MRS, and SPIE.

Akira SATOU: received Dr. Comp. Sci. from Univ. of Aizu, Japan, in 2008. He was an Assistant Lecturer, ISTC, Univ. of Aizu, in 2008 and CAIST, Univ. of Aizu, in 2009. He joined RIEC, Tohoku Univ., Japan, in 2010 as an Assistant Professor and was promoted to an Associate Professor in 2017. He is a member of IEEE (Senior), APS, JSAP, and IEICE.

[Papers]

[1] T. Otsuji, S.A. Boubanga-Tombet, A. Satou, D. Yadav, H. Fukidome, T. Watanabe, T. Suemitsu, A.A. Dubinov, V.V. Popov, W. Knap, V. Kachorovskii, K. Narahara, M. Ryzhii, V. Mitin, M.S. Shur, and V. Ryzhii, Nanophoton., vol. 11(9), pp. 1677-1696, Feb. 2022. DOI: 10.1515/nanoph-2021-0651 (invited, review)

[2] V. Ryzhii, M. Ryzhii, V. Mitin, M.S. Shur, and T. Otsuji, Phys. Rev. Appl., vol. 16(1), pp. 014001-1-12, July 2021. DOI: 10.1103/PhysRevApplied.16.014001

[3] A. Satou, Y. Omori, K. Nishimura, T. Hosotani, K. Iwatsuki, and T. Otsuji, J. Lightwave Technol., vol. 39 (10), pp. 3341-3349, May 2021. DOI: 10.1109/JLT.2021.3060795

Quantum-Optical Information Technology

Development of optoelectronic devices for quantum information and communication technology

Quantum-Optical Information Technology: Keiichi Edamatsu, Professor

[Research Target and Activities]

Our goal is to develop quantum information devices utilizing quantum interaction between photons and electrons in solids. In 2021, we have achieved (1) nonlocal generalized quantum measurements of bipartite spin products using entangled meter, (2) generation of spectrally factorable photon pairs via multi-order quasi-phase-matched spontaneous parametric downconversion, and (3) plasmon-enhanced single photon source directly coupled to an optical nanofiber.

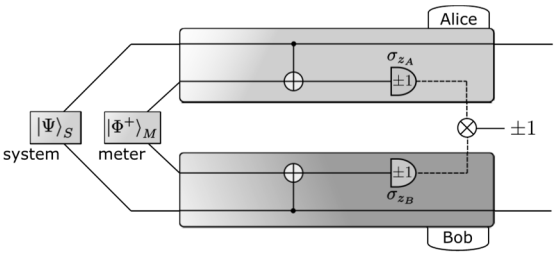


Fig. 1. Schematic of nonlocal generalized quantum measurement of bipartite spin products using entangled meter.

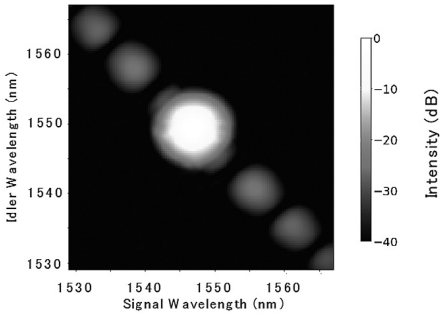


Fig. 2. Joint spectral distribution of a photon pair produced via multi-order quasi-phase-matched spontaneous parametric downconversion.

[Staff]

Professor: Keiichi Edamatsu, Dr.

[Profile]

Keiichi Edamatsu received B.S., M.S., and D.S. degrees in Physics from Tohoku University. He was a Research Associate in Faculty of Engineering, Tohoku University, a Visiting Associate in California Institute of Technology, and an Associate Professor in Graduate School of Engineering Science, Osaka University.

[Papers]

[1] P. Vidil and K. Edamatsu, "Nonlocal generalized quantum measurements of bipartite spin products without maximal entanglement", New J. Phys. **23**, 043004/1-10 (2021).
[2] M. Sadgrove, T. Yoshino, M. Sugawara, Y. Mitsumori, K. Edamatsu, "Optically Induced Sieve Effect for Nanoparticles near a Nanofiber Taper", Phys. Rev. Applied **16**, 044034/1-9 (2021).
[3] F. Kaneda, J. Oikawa, M Yabuno, F China, S. Miki, H Terai, Y. Mitsumori, and K. Edamatsu, "Generation of spectrally factorable photon pairs via multi-order quasi-phase-matched spontaneous parametric downconversion", arXiv 2111.10981 [quant-ph] (2021).
[4] B.H. Le and K. Edamatsu, "Error-disturbance uncertainty relations in Faraday measurements", arXiv 2112.14028 [quant-ph] (2021), to appear in Phys. Rev. A.
[5] M. Sugawara, Y. Xuan, Y. Mitsumori, K. Edamatsu, and M. Sadgrove, "Plasmon-enhanced polarized single photon source directly coupled to an optical fiber", arXiv:2203.01591 [quant-ph] (2022).

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Aims and Achievements of Human Information Systems Division

To realize advanced information communications systems, it is essential to understand and apply sophisticated information processing mechanisms of human being as well as to establish communications environments in that human can communicate anywhere, anytime without recognizing the communications tools. The aim of this division is to research and develop core and system technologies essential to advanced human friendly information and communications systems through understanding biological information generation mechanisms, human information processing mechanisms focusing on acoustic and visual inputs, and optimizing the communications environments.

To achieve the goal of the Division, six laboratories have been carrying out researches and developments in the following areas: (1) Electromagnetic Bioinformation Engineering, (2) Advanced Acoustic Information Systems, (3) Visual Cognition and Systems, (4) Information Content, (5) Real-world computing, (6) Nano-Bio Hybrid Molecular Devices, (7) Multimodal Cognitive System Laboratory.

The goals and achievements in the fiscal year 2020 of each laboratory are described in detail below.

(1) Electromagnetic Bioinformation Engineering

(Aims) This laboratory aims at obtaining the high accuracy sensor system for the signals from the human body or electric devices and at obtaining the system for approaching action to the human body by using the nano-scale controlled magnetic materials and by the development of the devices under the functions of the magnetics.

(Achievements) To develop a highly sensitive micro-vibration measuring system, we worked on the fabrication of high sensitive strain sensor itself and the design of detection circuits with ultra-low noise. The obtained system shows extra-high sensitivity up to 20kHz. On the work of high frequency magnetic field measuring system, we have succeeded to visualize the high-frequency current distribution in the circuit by measuring the magnetic field. We proposed a new mechanism for micro-power generator with vibration. Using a phase transformation of the magnetic materials, new power generation system was obtained.

(2) Advanced Acoustic Information Systems

(Aims) To propose high-definition communication systems that convey a rich and natural sense of presence. To this end, we are developing acoustic information processing technologies based on well-grounded knowledge of the human auditory system and the multimodal perception processes related to hearing.

(Achievements) We have focused on the mechanism of auditory and multisensory information processing. To enhance the perceptual reality induced by various multimodal contents, full-body vibration information, as well as audio-visual information, is added effectively. In this fiscal year, we investigated which physical characteristics of the vibration

affect the perceptual reality from the multimodal contents. We also investigated the effect of head rotation on sound localization, which is known as the multisensory process. In addition, we developed advanced acoustic systems, such as 3D virtual auditory displays, sound acquisition, and presentation systems. Although there are various realization methods of binaural synthesis, the accuracy of sound space information reproduced by the methods depends on the relationship between the implementation and the hardware specification using recording and reproduction. We proposed the design theory of the binaural synthesis using the spherical microphone array and head-related transfer functions.

(3) Visual Cognition and Systems

(Aims) To understand the vision-related brain functions in order to apply the knowledge to realize human oriented information communication systems.

(Achievements) Firstly, we revealed facilitation of visual processing near a hand with experiments to isolate hand-related effects from top–down attention, proprioceptive information from visual information, and the influence of response action. The results of experiment showed faster and more accurate processing of visual stimuli near a hand even there was no visual cue of the hand. This indicates that proprioceptive information of a hand contributed to attention near a hand. Since top-down attention was fixed at a location, we conclude that there is a process to facilitate vision around a hand independent from top-down attention. Secondly, we investigated collinear search impairment (CSI). Collinear search impairment (CSI) is a phenomenon where a task-irrelevant collinear structure impairs a target search in a visual display. Our experimental results showed the CSI regardless of the luminance contrast levels, which disagree with interpretation of the effect by an early vision mechanism, where contrast level should change the perception.

(4) Information Content

(Aims) As the Internet of Things (IoT) expands, everything around us coming online and joining integrated networks. Even everyday items like furniture are going digital. We view all artifacts, physical and digital, as content. Honoring the unique perspectives of people, systems, and the environments they inhabit, we study the interactions between types of content, with the ultimate goal of formulating cohesive, holistic, and intuitive approaches that promote efficiency, ease of use, and effective communication, we focus on content design to enhance living.

(Achievements) In this year, we primarily worked on a robotic-assisted dead-angle-free motion tracking system, a robotic office chair for manipulative posture guidance, a reconfigurable VR head-mounted display enabling peripheral real-world interactions, and a redirection technique while door opening or jumping in room-scale VR, Drone piloting interface that allows control of drone flight by touch using mobile AR.

(5) Real-world computing

(Aims) This laboratory aims at understanding the mechanism underlying adaptive and resilient behavior of animals from the viewpoint of decentralized control schemes.

(Achievements) The main contributions achieved in 2021 are summarized as follows: (1) we have proposed a mechanism for adjustment of limb movements during quadruped locomotion; (2) we have proposed a decentralized control mechanism for the body-limb coordination underlying sprawling locomotion; (3) we have proposed a local force feedback mechanism for undulatory swimming; (4) we have proposed a decentralized control scheme for adaptive locomotion of insects; (5) we have proposed a inter-limb coordination mechanism of centipedes that exploits flexible body.

(6) Nano-Bio Hybrid Molecular Devices

(Aims) Our research activities focus on the development of sophisticated molecular-scale devices through the combination of well-established microfabrication techniques and various soft materials, such as biomaterials and organic materials.

(Achievements) This year, we developed a new system for bilayer lipid membranes, in which a lateral voltage was introduced as a new input. We demonstrated that the new system could effectively modulate the ion-channel activity and the transmembrane currents of fullerene-doped bilayer membranes. We also launched Grant-in-Aid for Transformative Research Area (B) "Multicellular Neurobiocomputing" whose core technology is based on the control of the self-organized networks of neuronal cells. Finally, we utilized nanotube or nanoporous structures for the fabrication of gas sensors for CO detection and nanobubbles with bactericidal activity.

(7) Multimodal Cognitive System

(Aims) This group aims to study the basic mechanisms underlying multimodal cognitive systems, including vision, audition, tactile sensation, gustation and olfaction, together with the related groups such as the Advanced Acoustic Information Systems and the Visual Cognition and Systems groups.

(Achievements) In this year, we have done some studies about the followings; the interaction between onomatopoeia description of food texture and kinetic sensation and auditory sensation evoked during mastication; an interactive effect of colors and odors on evaluating the utilities of products. We have also started the cognitive studies about the effect of audition on binocular rivalry, the differences of attentional system of vision and of audition, the interactive mechanisms of audition with somatosensation, and the comparison of the effects of vision with audition on affection and arousal. We have published some articles about the interaction between food texture and kinetic sensation of masticatory muscle and the difference of gustatory evoked color-images with auditory evoked color-images

Electromagnetic Bioinformation Engineering

Communication with human body

Electromagnetic Bioinformation Engineering, Kazushi Ishiyama, Professor

[Research Target and Activities]

To develop a highly sensitive micro-vibration measurement system, fabrication of high sensitive strain sensors on Si wafer and the design of detection circuits with low noise were carried out. Imaging sensitivity of high frequency magnetic field measuring system was promoted by applying new technologies. We revealed that super-elastic materials were useful for a power generator to convert vibrational energy into electric energy.

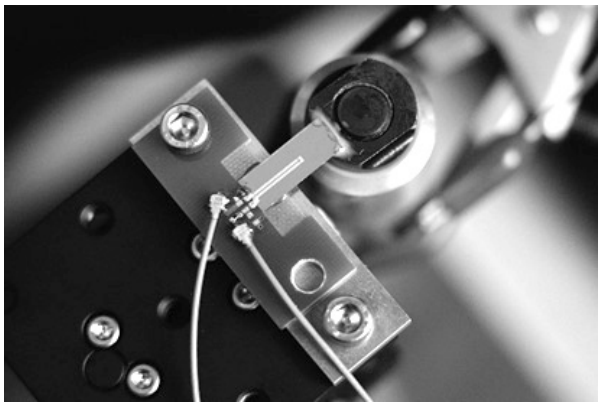

Figure 1 Vibration sensor using magnetostrictive thin film (@ 20kHz)

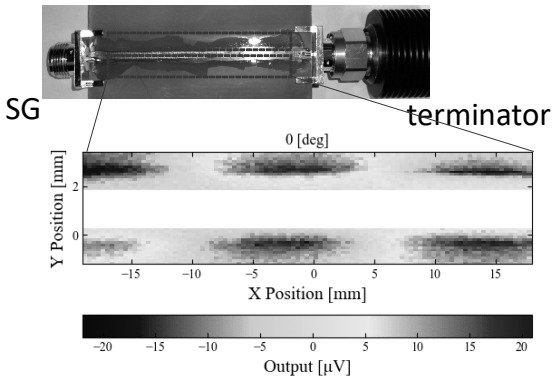

Figure 2 High frequency field visualization of the standing wave in microstrip line (@5GHz)

[Staff]

Professor: Kazushi Ishiyama, Dr.

[Profile]

Kazushi Ishiyama received his MS and PhD degrees in Electrical Engineering from Tohoku University in 1986 and 1993, respectively. His research interests are magnetics and magnetic applications.

[Papers]

[1] Taku Okada, Shun Fujieda, Shuichiro Hashi, Kazushi Ishiyama, Shigeru Suzuki, Satoshi Seino, Takashi Nakagawa, Takao A. Yamamoto, Vibration Power Generation Property of U-Shaped Unimorph Device Using Grain-Oriented Electrical Steel, MATERIALS TRANSACTIONS, 2021, vol. 62, no. 12, pp.1798-1801. doi: 10.2320/matertrans.MT-M2021079 .

[2] T. Mikami, S. Muroga, M. Tanaka, Y. Endo, S. Hashi and K. Ishiyama, "Estimation of Noise Suppression in MSL With Co-Zr-Nb Film Considering Impedance Matching," in IEEE Transactions on Magnetics, vol. 58, no. 2, pp. 1-5, Feb. 2022, Art no. 6100205, doi: 10.1109/TMAG.2021.3087257.

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Advanced Acoustic Information Systems

Towards high-level acoustic information communication systems

Advanced Acoustic Information Systems: Shuichi Sakamoto, Professor

[Research Target and Activities]

Our research goal is to clarify how humans process information through "hearing," which is one of the most important modalities in human perception. In addition, we investigate the multimodal processing of auditory and visual information, as well as proprioception. Our findings are applied towards the development of advanced acoustic communication systems and user interfaces, including the realistic and comfortable expression of three-dimensional (3D) sound spaces. One typical example is the development of new type of 3D auditory displays, which present spatial sound images by simulating the transfer functions for the sound paths from the sound sources to the listeners' external ears. Another example is the proposal of 3D sound field information sensing systems. These systems are expected to convey a high-quality virtual sound space, which is keenly sought for multimedia communications, cyberspace systems, and virtual reality systems.

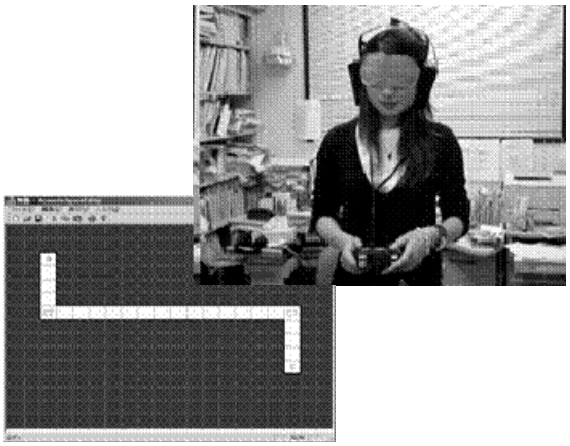


Fig. 1 Application for the training of spatial cognition using a high-definition virtual auditory display

In FY2021, we focused on how head-rotation affects sound localization. It is well known that sound localization is one of the multi-modal perceptual processes. We have reported that sound localization accuracy is degraded from the microscopic view when the head is rotating, although head rotation itself contributes to improving the sound localization. This year, we investigated that the reported sound-localization accuracy degrades irrespective of the rotation speed, even at a very slow rotation speed. Moreover, even during the very slow rotation or virtual head rotation induced by the change of visual information, degradation is observed [1,2]. These results suggest that a top-down process induced by listeners' conscious perception of the rotation may induce degradation.

[Staff]

Professor: Dr. Shuichi Sakamoto

[Profile]

Shuichi Sakamoto graduated from Tohoku University in 1997 and received his Ph. D. degree in 2004 also from Tohoku University. His research interests include human auditory and multisensory information processing and development of advanced multimodal information systems. From 2016 to 2019, he was serving as a board member of the Acoustical Society of Japan.

[Papers]

[1] A. Honda, K. Maeda, S. Sakamoto and Y. Suzuki, "Effects of visually induced self-motion on sound localization accuracy," Applied Sciences, 12(1), 173 (2022).
[2] A. Honda, S. Tsunokake, Y. Suzuki, and S. Sakamoto, "Auditory subjective-straight-ahead blurs during significantly slow passive body rotation," iPerception, 13(1), 1-5 (2022).
[3] A. Urviola, S. Sakamoto, and C. D. Salvador, "Ear centering for near-distance head-related transfer functions," Proc. International Conference on Immersive and 3D Audio (8 page manuscript) (2021).
[4] S. Shiraki, T. Sato, R. Ikeda, J. Suzuki, Y. Honkura, S. Sakamoto, Y. Katori, and T. Kawase, "Loudness functions for patients with functional hearing loss," International Journal of Audiology, 61(1), 59-65 (2022).

Visual Cognition and Systems Laboratory

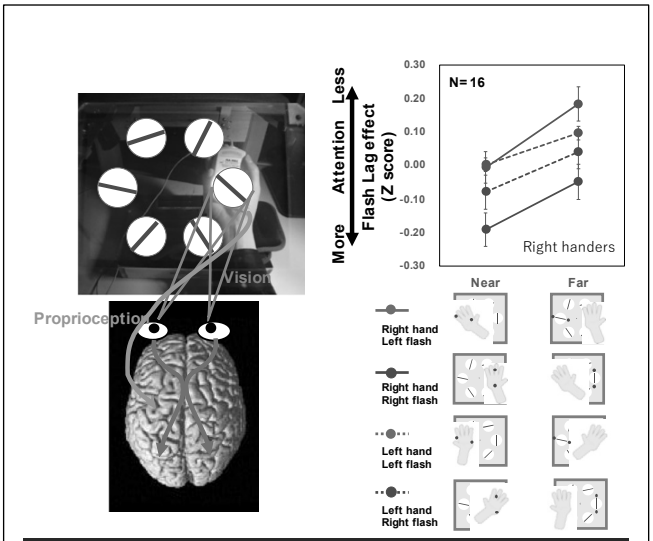
Understanding human visual system for the better communication with visual information

Visual Cognition and Systems: Satoshi SHIOIRI, Professor
Cognitive Brain Functions: Ichiro KURIKI, Associate Professor
Attention and Learning Systems: Chia-huei TSENG, Associate Professor

[Research Target and Activities]

Our target is to understand the vision-related brain functions in order to apply the knowledge to realize human oriented information communication systems. We made achievements in the fields of visual attention, depth perception and color perception.

Firstly, we revealed facilitation of visual processing near a hand with experiments to isolate hand-related effects from top–down attention, proprioceptive information from visual information, and the influence of response action. The results of experiment showed faster and more accurate processing of visual stimuli near a hand even there was no visual cue of the hand. This indicates that proprioceptive information of a hand contributed to attention near a hand. Since top-down attention was fixed at a location, we conclude that there is a process to facilitate vision around a hand independent from top-down attention. Secondly, we investigated collinear search impairment (CSI). Collinear search impairment (CSI) is a phenomenon where a task-irrelevant collinear structure impairs a target search in a visual display. Our experimental results showed the CSI regardless of the luminance contrast levels, which disagree with interpretation of the effect by an early vision mechanism, where contrast level should change the perception.



(Left) Stimulus configurations. The display was observed through a half mirror so that one of the discs was perceived as being on the palm of the hand, which was not visible during the experiment. Information of the hand location is transmitted to the brain through proprioception while vision conveys stimulus information on the display. (Right) Flash-lag effect (FLE) for right-handers. Solid and dashed lines show the right and left hand conditions, and red and blue symbols show the right and left flash conditions, respectively. The vertical axis indicates the FLE averaged over 16 observers after normalizing as Z-scores.

[Staff]

Professor : Satoshi Shioiri, Ph.D.
Associate Professor : Chia-huei Tseng, Ph.D.

[Profile]

Satoshi SHIOIRI Professor Shioiri graduated Tokyo Institute of Technology and received Dr. Eng in 1986. Then, he was a postdoctoral researcher at University of Montreal until May of 1989. From June of 1989 to April of 1990, he was a research fellow at Auditory and Visual Perception Laboratories of Advanced Telecommunications Research Institute. He moved to Chiba University at May of 1990, where he spent 15 years as an assistant professor, an associate professor, and a professor of Department of Image Sciences Department of Image, Information Sciences and Department of Medical Systems. In 2005, he moved to Tohoku University. Since then, he has been a professor of Research Institute of Electrical Communication of Tohoku University.

Chia-huei TSENG Dr. Tseng is an expert on visual attention, perception, and learning. She received her B.S. and B.M.S. from National Taiwan University and PhD from The University of California, Irvine, U.S.A.. She was a post-doc researcher at Laboratory of Vision Research at the Center for Cognitive Science, Rutgers University, New Jersey. She has designed science outreach activities to engage community participation in many Asian cities. She was the founder and director of Baby Scientist Program and Infant Research Lab in Hong Kong. Before joining Tohoku University as associate professor in 2016, she was a university professor in Taiwan and Hong Kong.

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Information Content

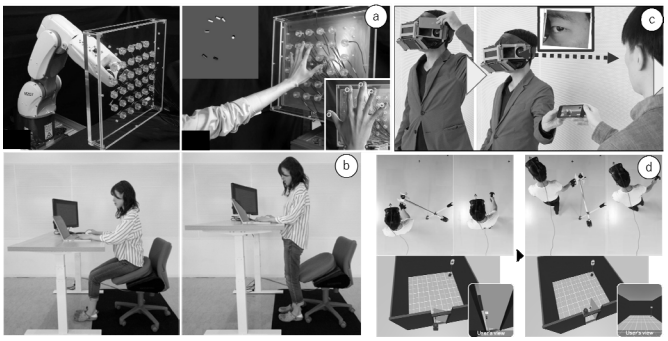
Technologies for Interactive Content

Interactive Content Design	Yoshifumi KITAMURA,	Professor
Human-Content Interaction	Kazuki TAKASHIMA,	Associate Professor

[Research Target and Activities]

As the Internet of Things (IoT) expands, everything around us coming online and joining integrated networks. Even everyday items like furniture are going digital. We view all artifacts, physical and digital, as content. Honoring the unique perspectives of people, systems, and the environments they inhabit, we study the interactions between types of content, with the ultimate goal of formulating cohesive, holistic, and intuitive approaches that promote efficiency, ease of use, and effective communication, we focus on content design to enhance living.

In this year, we primarily worked on a robotic-assisted dead-angle-free motion tracking system (Fig.a), a robotic office chair for manipulative posture guidance (Fig.b, [2]), a reconfigurable VR head-mounted display enabling peripheral real-world interactions (Fig.c, [1]), and a redirection technique while door opening in room-scale VR (Fig.d)



[Staff]

Professor: Yoshifumi Kitamura, Dr.
Associate Professor: Kazuki Takashima, Dr.
Assistant Professor: Kazuyuki Fujita, Dr.
Assistant Professor: Kaori Ikematsu, Dr.
Assistant Professor: Miao Cheng, Dr.

[Profile]

Yoshifumi Kitamura: Since 2010, Yoshifumi Kitamura has been Professor in the Research Institute of Electrical Communication, Tohoku University. Prior to arriving at Tohoku, he was an Associate Professor at Graduate School of Engineering, and Graduate School of Information Science and Technology, Osaka University. While working at ATR Communication Systems Research Laboratories, he focused on sophisticated user interfaces in virtual environments. His first formal appointment was in the Information Systems Research Center Canon Inc., where he was involved in research on artificial intelligence, image processing, computer vision, and 3D data processing. His formal education was obtained at Osaka University, B.Sc (1985); M.Sc. (1987); and Ph.D. (1996).

Kazuki Takashima: He received a Ph.D from the Information Science and Technology at Osaka University in 2008. After working at Osaka University (2008 - 2011). He joined the Research Institute of Electrical Communication, Tohoku University as an assistant professor in 2011, and became an associate Professor in 2018.

[Papers]

[1] Isamu Endo, Kazuki Takashima, Maakito Inoue, Kazuyuki Fujita, Kiyoshi Kiyokawa, Yoshifumi Kitamura, ModularHMD: A Reconfigurable Mobile Head-Mounted Display Enabling Ad-hoc Peripheral Interactions with the Real World, Proc. Symposium on User Interface Software and Technology, 100-117, October 2021.

[2] Kazuyuki Fujita, Aoi Suzuki, Kazuki Takashima, Kaori Ikematsu, Yoshifumi Kitamura, TiltChair: Manipulative Posture Guidance by Actively Inclining the Seat of an Office Chair, Proc. Conference on Human Factors in Computing Systems, No. 228, 1-14, May 2021.

Real-world Computing

Toward Understanding Design Principle for Life-like Resilient Systems

Real-world Computing, Akio Ishiguro, Professor

[Research Target and Activities]

Living organisms exhibit surprisingly adaptive and versatile behavior in real time under unpredictable and unstructured real world constraints. Such behaviors are achieved via spatiotemporal coordination of a significantly large number of bodily degrees of freedom. Clarifying these remarkable abilities enable us to understand life-like complex adaptive systems as well as to construct truly intelligent artificial systems. A prominent concept for addressing this issue is "autonomous decentralized control", in which non-trivial macroscopic functionalities are emerged via spatiotemporal coordination among vast amount of autonomous components that cannot be explained solely in terms of individual functionality. We study the design principle of autonomous decentralized systems that exhibit life-like resilient behaviors from the viewpoints of robotics, mathematics, nonlinear science, and physics.

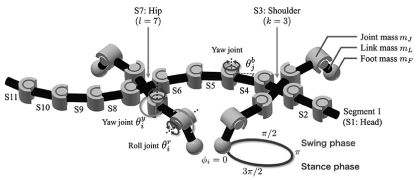


Fig.1: Legged robot that can coordinate body and limb motions like sprawling quadrupeds

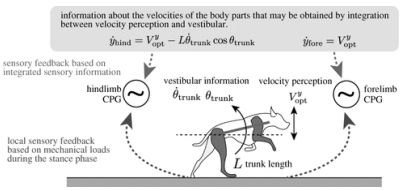


Fig.2: Simple decentralized control mechanism that enables limb adjustment for adaptive quadruped running

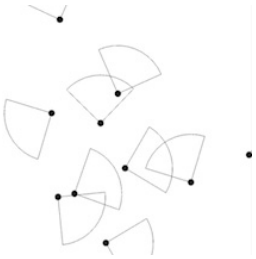


Fig.3: Decentralised control of multiple mobile agents for quick, smooth, and safe movement

[Staff]

Professor: Akio ISHIGURO, Dr.
Associate Professor: Takeshi KANO, Dr.
Assistant Professor: Akira FUKUHARA, Dr.
Assistant Professor: Kotaro YASUI, Dr.

[Profile]

Akio ISHIGURO received B.E., M.E., and Ph.D. degrees from Nagoya University in 1987, 1989, and 1991, respectively. From 1991 to 1997, he was with Nagoya University as an assistant professor. From May 1997 to 2006, he was an associate professor, Nagoya University. From 2006 to 2011, he was a professor of the Graduate School of Engineering, Tohoku University. Since April 2011, he has been a professor of Research Institute of Electrical Communication, Tohoku University. His main research interests are in bio-inspired robotics, nonlinear dynamics. He received 2004 IROS Best Paper Award, 2008 Ig Nobel Prize (Cognitive Science Prize), 2012 IEEE/RSJ JCTF Novel Technology Paper Award for Amusement Culture Finalist, Living Machines 2012 Best Paper Award.

[Papers]

[1] Suzuki, S., Kano, T., Ijspeert, A. J., & Ishiguro, A. (2021). Spontaneous Gait Transitions of Sprawling Quadruped Locomotion by Sensory-Driven Body–Limb Coordination Mechanisms. Frontiers in Neurorobotics, 15.

[2] Fukuhara, A., Koizumi, Y., Baba, T., Suzuki, S., Kano, T., & Ishiguro, A. (2021). Simple decentralized control mechanism that enables limb adjustment for adaptive quadruped running. Proceedings of the Royal Society B, 288(1962), 20211622.

[3] Kano, T., Iwamoto, M., & Ueyama, D. (2021). Decentralised control of multiple mobile agents for quick, smooth, and safe movement, Physica A: Statistical Mechanics and its Application,572, 12, 125898.

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Nano-Bio Hybrid Molecular Devices

Development of novel bio-devices through the combination of nanotechnology and biomaterials

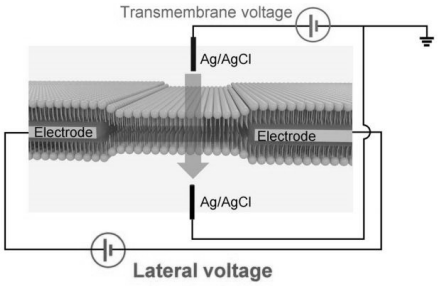
Nano-Bio Hybrid Molecular Devices: Ayumi Hirano-Iwata, Professor

[Research Target and Activities]

Our research activities focus on the development of sophisticated molecular-scale devices through the combination of well-established microfabrication techniques and various soft materials.

1. Construction of a new measurement system for artificial lipid bilayer membranes

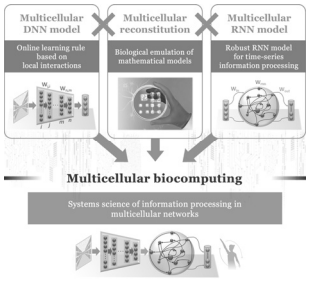
We developed a new measurement system for artificial lipid bilayer membranes, in which a lateral voltage was introduced as a new input in addition to the traditional transmembrane voltage. We demonstrated that the new system could effectively modulate the ion-channel activity and the performance of hybrid devices based on fullerene-doped bilayer membranes. [Faraday Discuss., **233**, 244–256 (2022).]



New system for artificial lipid bilayer.

2. In vitro reconstitution of neuronal network functions on microfabricated substrates

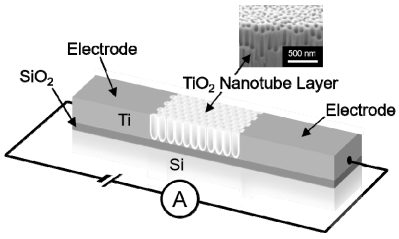
In collaboration with a member of the newly launched Grant-in-Aid for Transformative Research Area (B) "Multicellular Neurobiocomputing" (MEXT KAKENHI), we developed a novel microelectrode technology to deliver localized stimulation to cultured neuronal networks grown on microfabricated substrates. [Electrochemistry, **89,** 348–354 (2021).]



Multicellular Neurobiocomputing.

3. TiO_2 nanotube-based gas sensor / Bacterial activity of nanobubbles generated using porous alumina films

We developed a TiO_2 nanotube-based gas sensor for precisely detecting trace amounts of CO in a gas mixture. We also confirmed the bactericidal activity of nanobubbles generated using porous alumina films. [Sens. Act. B, **361**, 131732 (2022); Langmuir, **37**, 9883–9891 (2021).]



TiO_2 nanotube-based gas sensor.

[Staff]

Professor: Ayumi Hirano-Iwata, Dr.

[Profile]

Ayumi Hirano-Iwata 2016– RIEC, Tohoku University, Japan, Professor, Doctor of Science. Memberships: The Japan Society of Applied Physics, The Japan Society of Vacuum and Surface Science.

[Papers]

[1] T. Ma, M. Sato, M. Komiya, K. Kanomata, T. Watanabe, X. Feng, R. Miyata, D. Tadaki, F. Hirose, Y. Tozawa, A. Hirano-Iwata, "Lateral voltage as a new input for artificial lipid bilayer systems". Faraday Discuss., **233**, 244–256 (2022).

[2] K. Hattori, H. Kurakake, J. Imai, T. Hashimoto, M. Ishida, K. Sato, H. Takahashi, S. Oguma, H. Yamamoto, A. Hirano-Iwata, T. Tanii, "Selective stimulation of a target neuron in micropatterned neuronal circuits using a pair of needle electrodes", Electrochemistry, **89**, 348–354 (2021).

[3] K. Iwata, H. Abe, T. Ma, D. Tadaki, A. Hirano-Iwata, Y. Kimura, S. Suda, M. Niwano, "Application of neural network based regression model to gas concentration analysis of TiO_2 nanotube-type gas sensors", Sens. Act. B: Chemical, **361**, 131732 (2022).

Research Targets and Activities of Systems & Software Division

The goal of System & Software Division is to realize ideal ubiquitous environment where everyone can freely communicate in real-time with anyone, anywhere, and at any time through any kind of information. With the reorganization of RIEC in FY2016, our division has the following seven research fields related to such high-level ubiquitous systems, software and contents by integrating computer and communication:

— Software Construction: Reliable and high-level software.
— Computing Information Theory: Fundamental theory of new software.
— Communication Network: Symbiotic computing.
— Environmentally Conscious Secure Information System: Embedded system security
— Soft Computing Integrated System: Brainmorphic hardware.
— New Paradigm VLSI System: Post-binary CMOS-based VLSI computing.
— Structure of Information Society (Visitor Section).

An overview of research results from Apr. 2021 to Mar. 2022 of these fields except the visitor section is described in this section.

(1) Software Construction

The Software Construction laboratory researches on foundations for flexible and reliable programming languages as a basis for realizing innovated programming languages. In 2021, the final year of the laboratory, in addition to foundational research, we have made special efforts to complete SML#, a new statically typed polymorphic language that embodies the laboratory's wide-range of research results from proof theory for compilation to low-level memory management. Compared with conventional functional languages, SML# realizes important practical features that have not been well supported in existing functional languages, including seamless integration of SQL and direct interface to C. In this year, we have set up SML# GitHub repository and SML# GitHub page (https://smlsharp.github.io/en/about/features/) for releasing and developing SML# as open source software. We have also published textbooks (in Japanese) on learning SML# programming and on studying compiler structures and principles through SML#.

(2) Computing Information Theory

Continuing on from last year, we have studied formal language theory, which is the theoretical basis for software verification, as well as bidirectional transformation techniques applied to data synchronization and data sharing. One of the results of our research is the relationship between classes of tree transducers, which we discovered last year. In FY2021, we continued our research on the relationship between classes of different types of tree transducers. We improved the proof of equivalence of expressive power between different classes of tree transducers and succeeded in clarifying the position of this research by systematically summarizing the results of previous research. We also discovered a computational model for idempotent functions, which is one of the basis of a bidirectional transformation. This computational model, which adds syntactic constraints to the Turing machine, exactly covers all computable idempotent functions, and we have succeeded in

proving its universality. Combined with the computation model for involutory functions discovered in the previous fiscal year, this computation model is expected to be applied to the characterization of programming languages specialized for bidirectional transformations.

(3) Communication Network Systems

We promoted the following research on information networking technologies that support various human activities and their application. In the area of Internet congestion control, we proposed a novel method to maintain per-flow throughput fairness by estimating the behavior of competing flows with machine learning-based algorithms. For energy optimization in the digital twin system, we formulated the power consumption of the edge-cloud computing system for constructing the digital twin from massive information from sensors and cameras, and proposed an optimizing framework for minimizing the power consumption. Furthermore, in the research on agent-based IoT and its applications, we prototyped and evaluated a mobile agent framework for small IoT devices. We also conducted a study of a data reduction method for using LPWA for out-of-band management of network equipment.

(4) Environmentally Conscious Secure Information System

We are studying future secure information communication systems from theories to implementation technologies for constructing advanced information and communication infrastructures in a safe and secure manner. In this year, we developed a novel technology to implement tamper-resistant post-quantum cryptography (PQC) software and hardware which is known to be resistant to quantum computers. The developed technology is effective for 8 out of 9 types of PQC international standard candidates, and will contribute to improving the security of PQC-equipped products in the future. We also developed a technology to detect malicious functions (hardware trojans) inserted in hardware in a fast and complete manner, and demonstrated that it can be applied to large-scale and complicated IC design data that was difficult until now. Furthermore, we showed the threats that the structure and parameters of machine learning hardware could be estimated from side-channel information (e.g., power consumption and radiated electromagnetic waves), and clarified effective countermeasures against them.

(5) Soft Computing Integrated System

We are working on a novel high-performance, highly-efficient, flexible, and robust brain-inspired brainmorphic computer hardware system, in particular, through physical complex-networked dynamical process using an analog VLSI as a core component. Results of this year include the followings. (i) We proposed a network construction technique for the chaotic neural network reservoir with mutual connections using only two layers by introducing a cyclic updating scheme of neuronal states. We then implemented a proof of concept chip of a TSV/μbump 3D stacked cyclic chaotic neural network reservoir LSI. The experiments of the chip and emulations of networks confirmed the validity the chip. (ii) We improved our mathematical model of neuron-like and synapse-like spintronics devices for integrated circuit and learning neural network designs. (iii) We proposed 6 online learning algorithms for real-time additional learning of reservoir neural networks. Performances of

these algorithms were compared through simulations. (iv) We clarified the effects of local memory (refractoriness) and max-gain of the neuron in the chaotic neural network reservoir on word recognition performance through simulations.

(6) New Paradigm VLSI System

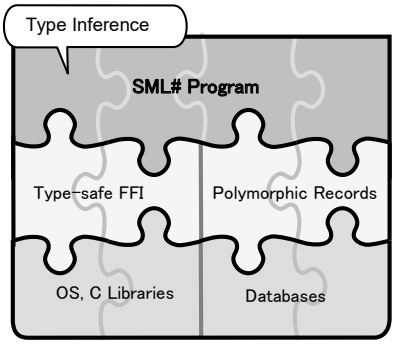
Our research activity is to solve the several limitations such as power dissipation, performance and reliability due to the present binary-CMOS-based VLSI computing. The key approach to breaking through such limitations is primarily the following two ways: the logic-in-memory architecture based on nonvolatile logic, and the brainware LSI (BLSI) computing, which would open up a novel VLSI chip paradigm, called a "new-paradigm VLSI system." In FY 2020, we have preliminarily achieved the following two activities. (a) First, we have succeeded in realizing a high-performance non-volatile memory based on a spintronics/semiconductor-hybrid LSI fabrication technology. The world's first dual-port structure for a memory that uses a 3-terminal spintronics device (called SOT-MTJ device) as a next-generation memory that has no volatility, high endurance, and high-speed data read/write accessibility. It has demonstrated 60MHz-write and 90MHz-read operations due to its simultaneous parallel data-access operation. (b) We have also succeeded that the problem size solved by our method in the combinatorial optimization problem is about 16 times larger than that of the quantum-annealing machine in D-Wave Systems. This is the method based on stochastic logic which is known as a kind of probabilistic-computing techniques. Our method is an algorithm that can be used in a general classical computer, but it is the result of succeeding in relatively increasing the rate of convergence to the optimum solution, compared with the D-wave machine. As a result, our stochastic-logic-based method is practical for realization against the D-wave machine that requires ultra-low temperature operation, and its performance is significantly higher than that of the conventional ones. The results of this year's research, including the above, are 12 academic journal papers, 4 peer-reviewed international conference papers, and 3 invited lectures (including 3 international conference), which includes IEEE Journal of Solid-State Circuits, one of the highest international academic journals on cutting-edge integrated circuit technology, and IEEE Transactions on Neural Networks and Learning Systems (published online at March 30, 2022), one of the highest academic journals in the field of neural-network circuits and systems (IF: 10.451).

Software Construction Laboratory

Foundations for Developing High-level and Reliable Programming Languages

Software Construction Atsushi Ohori, Professor
Reliable Software Development Katsuhiro Ueno, Associate Professor (until September 2021)

[Research Target and Activities]



SML#: a high-level and reliable language

Today's software systems are becoming more and more complicated due to the need of integrating various computation resources available in the Internet. A key to control the complexity and to enhance the reliability of such a system is to develop a high-level programming language that can directly represent various resources and automatically detect potential inconsistencies among the components in a system. Based on this general observation, our research aims at establishing both firm theoretical basis and implementation method for flexible yet reliable programming languages for advanced applications. Research topics on theoretical foundations include: logical foundations for compilation and type-directed compilation for polymorphic languages. We are also developing a new practical ML-style programming language, SML#, which embodies some of our recent results such as record polymorphism, direct C interface, and seamless integration of SQL.

In 2021, the final year of the laboratory, in addition to the above and other theoretical research, we have made special efforts to complete and disseminate SML#. We have set up SML# GitHub repository and SML# GitHub page (https://smlsharp.github.io/en/about/features/) for releasing and developing SML# as open source software. We have also published textbooks (in Japanese) on learning SML# programming [2] and on studying compiler structures and principles through SML# [3].

[Staff]

Professor : Atsushi Ohori, Ph.D.
Associate Professor : Katsuhiro Ueno, Dr. (until September 2021)
Assistant Professor : Kentaro Kikuchi, Dr.

[Profile]

Atsushi Ohori. He was born in 1957. He received his BA degree in Philosophy from University of Tokyo, 1981; Ph.D. degree in Computer and Information Science from University of Pennsylvania, 1989. He worked for Oki Electric Industry from 1981 until 1993. In 1993, he joined RIMS, Kyoto University as an Associate Professor. In 2000, he joined Japan Advanced Institute of Science and Technology as a Professor. In 2005, he moved to RIEC, Tohoku University as a Professor.

Katsuhiro Ueno. He was born in 1981. He received the Doctor of Philosophy (Information Sciences) degree from Tohoku University, 2009. He joined Research Institute of Electrical Communication (RIEC), Tohoku University as an assistant professor in 2009. Since 2016 until September 2021, he had been an associate professor at the same institute.

[Papers (conference presentations) and books]

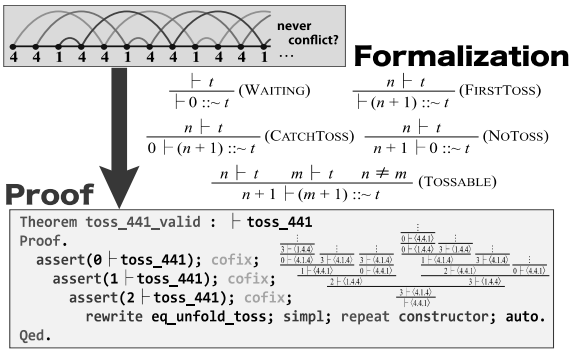
[1] Atsushi Ohori, Katsuhiro Ueno: A Compilation Method for Dynamic Typing in ML. In Proceedings of the 19th Asian Symposium on Programming Languages and Systems (APLAS'21), LNCS 13008, pp. 140-159, 2021, DOI: 10.1007/978-3-030-89051-3_9.
[2] Atsushi Ohori, Katsuhiro Ueno: Practical ML Programming with SML# (in Japanese), April 2021, 242 pages, Kyoritsu Shuppan Co Ltd., ISBN:9784320124714.
[3] Atsushi Ohori: Compiler: Principles and Structures (in Japanese), September 2021, 196 pages, Kyoritsu Shuppan Co Ltd., ISBN:9784320124783.

Computing Information Theory

Filling the Gap between Humans and Computers

Computing Information Theory Keisuke Nakano, Professor

[Research Target and Activities]



Notwithstanding that programming is one of the most typical methods for a human to communicate with a computer, there is a significant gap between programs that are recognizable for humans and those that are efficiently executed by computers. Programs described as humans think are highly readable but are not always efficient. On the other hand, programs described with carefully considering the behavior of computers show much better performance in time and space but are very complicated and hardly maintainable. Our ultimate goal is to fill the gap between humans and computers in programming.

More specifically, our research topics include *program transformation* and *program verification*. Program transformation is to automatically derive well-tuned and efficient programs from human-readable ones; Program verification is to statically (that is, without running) check if human-written but well-tuned complicated programs behave as the programmers expect for any input. To this end, we deeply study the theory of formal tree languages, such as tree automata and tree transducers, which has a close relationship with the program transformation and verification. Besides that, we are working on formalizing relevant results in mathematics and theoretical computer science on a proof assistant to make our theory more robust.

[Staff]

Professor : Keisuke Nakano, Dr.
Assistant Professor : Kazuyuki Asada, Dr.

[Profile]

Keisuke Nakano received his Ph.D. from Kyoto University in 2006. He worked as a researcher at the University of Tokyo from 2003 to 2008. He has been an assistant professor from 2008 to 2012 and an associate professor from 2012 to 2018 at the University of Electro-Communications. Since 2018, he has been a professor at the Research Institute of Electrical Communication. His research interests include formal language theory, programming language theory, and functional programming. He is a member of ACM, JSSST, and IPSJ.

[Papers]

[1] Keisuke Nakano. Time-symmetric Turing machines for computable involutions, Science of Computer Programming, Volume 215, 1 March 2022, 102748.
[2] Idempotent Turing Machines, 46th International Symposium on Mathematical Foundations of Computer Science (MFCS 2021), Tallin, Estonia (hybrid), August 2021.
[3] Keisuke Nakano. A Tangled Web of 12 Lens Laws, Proc. of 13th International Conference on Reversible Computation (RC 2021), Nagoya, Japan Online, July 2021.
[4] Kazuki Watanabe, Clovis Eberhart, Kazuyuki Asada, and Ichiro Hasuo. A Compositional Approach to Parity Games, Proc. 37th Conference on the Mathematical Foundations of Programming Semantics (MFPS 2021), Salzburg (online, hybrid), EPTCS 351, 2021, pp. 278-295

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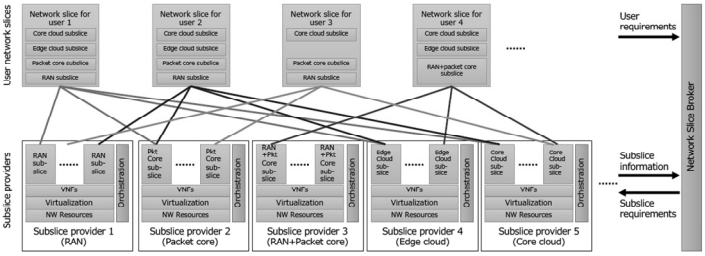
Communication Network Systems

Information Network Architecture for the IoT Society

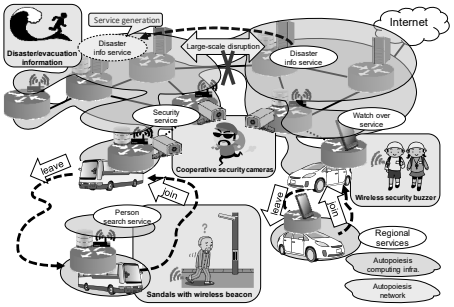
Information Network Architecture: Go Hasegawa, Professor
Intelligent Network: Gen Kitagata, Associate Professor

[Research Target and Activities]

In this year, the following studies had been done. (a) Research on mobile network architecture foro accommodating a large number of Machine-to-Machine (M2M) and Internet of Things (IoT) terminals (b) Research on function placement problems in the mobile networks with edge computing (c) Research on new network architecture for future beyond-5G networks, that is based on a fine and heterogeneous resolution of network slicing and introducing sub-slice provider and network slice broker for efficient and scale-free network slice construction. (d) Research on Internet congestion control for fairness and throughput improvement (e) Research and development of essential technologies for an autopoietic computing platform which is autonomously formed by IoT devices in a distributed manner utilizing software agent technology.



Network slicing architecture for beyond-5G networks.



An image of autopoietic networking.

[Staff]

Professor : Go Hasegawa, Dr.
Associate Professor : Gen Kitagata, Dr.

[Profile]

Go Hasegawa received the M.E. and D.E. degrees in Information and Computer Sciences from Osaka University, Japan, in 1997 and 2000, respectively. From July 1997 to June 2000, he was Research Assistant of Graduate School of Economics, Osaka University. From 2000 to 2018, he was an Associate Professor of Cybermedia Center, Osaka University. He is now a Professor of Research Institute of Electrical Communication, Tohoku University. His research work is in the area of information network architecture. He is a member of the IEEE and IEICE.

Gen Kitagata is an associate professor of the Research Institute of Electrical Communication of Tohoku University, Japan. He received a doctoral degree from the Graduate School of Information Sciences, Tohoku University in 2002. His research interests include agent-based computing, intelligent networking, and resilient networking. He is a member of IEICE, IPSJ.

[Papers]

[1] Satoshi Utsumi and Go Hasegawa, Refining Calculation Algorithm for Packet Pacing Rate of BBR, Proceedings of IEEE CQR 2021, May 2021.
[2] Go Hasegawa, Satoshi Hasegawa, Shin-ichi Arakawa, and Masayuki Murata, UONA: User-Oriented Network slicing Architecture for beyond-5G networks, Proceedings of IEEE ICC 2021, June 2021.

Environmentally Conscious Secure Information System

Advanced information security technology

Environmentally Conscious Secure Information System, Naofumi Homma, Professor

[Research Target and Activities]

We are studying future secure information communication systems from theories to implementation technologies for constructing advanced information and communication infrastructures in a safe and secure manner. In this year, we have discovered and reported a power analysis attack on post-quantum cryptography (PQC). The attack that we found is applicable to most PQC schemes, as it exploits a common structure among PQCs. We have developed its countermeasure, and confirmed the effectiveness through an experiment. In addition, we have also evaluated RISC-V processor security, reported a physical vulnerability of its security scheme called isolated execution, and developed its low-overhead countermeasure. Furthermore, we have developed technologies for realizing secure information systems, including automatic verification/synthesis system of tamper-resistance cryptographic hardware, hardware architectures for efficient PQC computation, security evaluation method for cryptographic modules based on deep learning, and formal (mathematical) proof system for functional verification of cryptographic hardware.

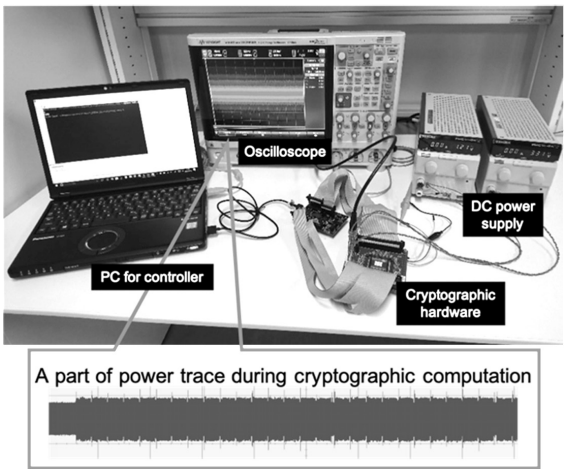


Fig. 1: Experiment for security evaluation of cryptographic hardware

[Staff]

Professor: Naofumi Homma, Ph. D
Assistant Professor: Rei Ueno, Ph. D

[Profile]

Naofumi Homma received the PhD degrees in information sciences from Tohoku University, Sendai, Japan, in 2001. Since 2016, he has been a Professor in the Research Institute of Electrical Communication, Tohoku University. In 2009-2010 and 2016-2017, he was a visiting professor at Telecom ParisTech, Paris, France. He received a number of awards including the IACR CHES Best Paper Award in 2014, the JSPS Prize in 2018, and the German Innovation Award in 2018.

[Papers]

[1] K. Xagawa *et al*., "Fault-Injection Attacks against NIST's Post-Quantum Cryptography Round 3 KEM Candidates," In *ASIACRYPT*, pp. 33—61, 2021.
[2] R. Ueno *et al*., "Curse of Re-encryption: A Generic Power/EM Analysis on Post-Quantum KEMs," *IACR Transactions on Cryptographic Hardware and Embedded Systems*, Vol. 2022, Issue 1, pp. 296–332, 2021.
[3] S. Nashimoto *et al*., "Bypassing Isolated Execution on RISC-V using Side-Channel-Assisted Fault-Injection and Its Countermeasure," *IACR Transactions on Cryptographic Hardware and Embedded Systems*, Vol. 2022, Issue 1, pp. 28–68, 2021.
[4] A. Ito *et al*., "Imbalanced Data Problem in Deep-Learning Based Side-Channel Attacks: Analysis and Solution," *IEEE Transactions on Forensics & Security*, Vol. 16, pp. 3790–3802, 2021.
[5] R. Ueno *et al*., "A Systematic Design Methodology of Formally-Proven Side-Channel-Resistant Cryptographic Hardware," *IEEE Design & Test*, Vol. 38, Issue 3, pp. 84–92, 2021.
[6] A. Ito *et al*., "Efficient Formal Verification of Galois-Field Arithmetic Circuits Using ZDD Representation of Boolean Polynomials," *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. 41, Issue 3, pp. 794–798, 2021.

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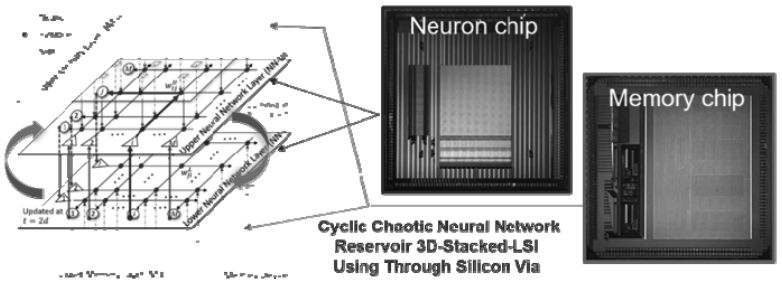
Soft Computing Integrated System

Brainmorphic Computing Hardware System

Soft Computing Integrated System **Yoshihiko Horio, Professor**

[Research Target and Activities]

We are working on a novel high-performance, highly-efficient, flexible, and robust "brainmorphic" computing hardware system through physical complex-networked dynamical process using novel nano-scale devices. Toward the final goal, we are developing integrated circuit and device technologies suitable for the brainmorphic computer systems, ultra-low-power asynchronous neural network systems, neuron-like and synapse-like spintronics devices, and a brainmorphic system architecture. During the FIY 2021; 1) We implemented a proof-of-concept chip for a cyclic-updating chaotic neural network reservoir (CNNR) integrated circuit using TSV/μbump 3D stacked IC technology; 2) We improved device models for neuron-like and synapse-like spintronics devices for IC and neural network designs; 3) We proposed six online learning algorithms for reservoir neural networks; and 4) We clarified the effects of the local memory parameters on the word recognition performance of CNNR.



[Staff]

Professor : Yoshihiko Horio, Ph.D.

[Profile]

Yoshihiko Horio received the B.E., M.E., and Ph.D. degrees in electrical engineering from Keio University, Japan, in 1982, 1984, and 1987, respectively. He is currently a Professor with the Research Institute of Electrical Communication, Tohoku University, Japan. From 1987 to 2016, he was with Department of Electronic Engineering, Tokyo Denki University, Japan, being a Professor from 2000. From April 1992 to March 1994, he was a Visiting Professor at Center for Telecommunications Research, Columbia University, U.S.A. His current research interests are in the area of neuromorphic and brainmorphic hardware systems based on complex physical dynamics, mixed analog/digital VLSI circuit design, and high-order brain-inspired VLSI systems with consciousness, self, and embodiment. Dr. Horio received the 3rd Hiroshi Ando Memorial Young Engineer Award (1990), the IEEE Myril B. Reed Best Paper Award (1991), NCSP Best Paper Awards (2005, 2007, 2008, 2013, 2020), IEEE NDES Best Paper Awards (2005, 2007), ISCS-ISIS Best Paper Award (2008), JSAP Outstanding Paper Award (2019), NOLTA2020 Best Paper Award (2020), IEICE NOLTA Lifetime Achievement Award (2016), Fellow, IEICE (2018), and Emeritus Professor of Tokyo Denki University (2020). .

[Papers]

[1] K. Fukuda and Y. Horio, "Analysis of dynamics in chaotic neural network reservoirs: Time-series prediction tasks," Nonlinear Theory and Its Applications, IEICE, vol. 12, no. 4, pp. 639-661, DOI: 10.1587/nolta.12.639, October 1, 2021.

[2] K. Fukuda, Y. Horio, T. Orima, K. Kiyoyama, and M. Koyanagi, "Cyclic reservoir neural network circuit for 3D IC implementation," Nonlinear Theory and Its Applications, IEICE, vol. 12, no. 3, pp. 309-322, DOI: 10.1587/nolta.12.309, July 1, 2021. (Invited Paper).

[3] Y. Horio, T. Orima, K. Kiyoyama, and M. Koyanagi, "Implementation of a chaotic neural network reservoir on a TSV/μ bump stacked 3D cyclic neural network integrated circuit," in Proc. 2021 IEEE International 3D System Integration Conference, paper number 5b (4 pages), Online, November 16-19, 2021.

New Paradigm VLSI System Research Group

Realization of a New-Paradigm VLSI-Computing World

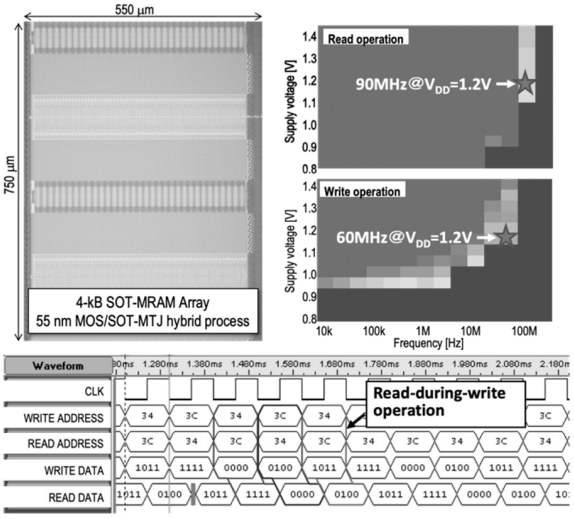


Fig. 1. A dual-port nonvolatile memory using 3-terminal spintronics devices (SOT-MRAM) achieving high-speed read / write / read-during-write operations

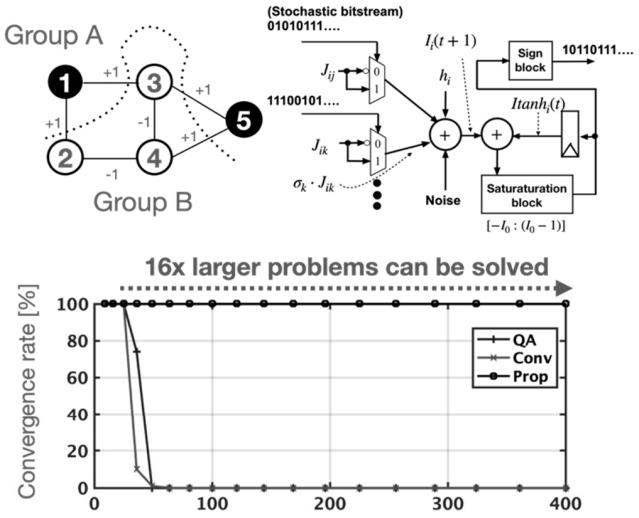


Fig. 2. Proposed simulated-annealing method can solve 16x larger combinational optimization problems than the quantum annealing machine, D-wave.

New Paradigm VLSI System: Takahiro Hanyu, Professor
New Paradigm VLSI Design: Masanori Natsui, Associate Professor
New Paradigm VLSI Computing: Naoya Onizawa, Associate Professor

[Research Target and Activities]

Rapid progress in recent deep submicron regime has led the capability to realize giga-scaled embedded systems on a chip (SoC), while performance degradation of SoCs due to wiring complexity, power dissipation and device-characteristic variation are increasingly getting serious problems in the recent Very Large Scale Integration (VLSI) chip. Our research activity is to solve the above problems primarily by the following two ways: the logic-in-memory architecture based on nonvolatile logic, and the brainware LSI (BLSI) computing, which would open up a novel VLSI chip paradigm, called a "new-paradigm VLSI system."

This year, we have succeeded to design and implement the 3-terminal magnetic tunnel junction (MTJ)-based nonvolatile memory (MRAM) (Fig. 1), and the fast-converging simulated annealing of combinational optimization problems based on integral stochastic computing (Fig. 2).

[Staff]

Professor : Takahiro Hanyu, Dr.
Associate Professor : Masanori Natsui, Dr.
Associate Professor : Naoya Onizawa, Dr.

[Profile]

Takahiro Hanyu received the D.E. degrees in Electronic engineering from Tohoku University, Sendai, Japan, in 1989. His general research interests include multiple-valued current-mode logic and its application to high performance and low-power arithmetic VLSIs.

Masanori Natsui received the Ph.D. degrees in information Sciences from Tohoku University, Sendai, Japan, in 2005. His research interest includes automated circuit design technique, nonvolatile-based circuit architecture and its application, and design of high speed low-power integrated circuits.

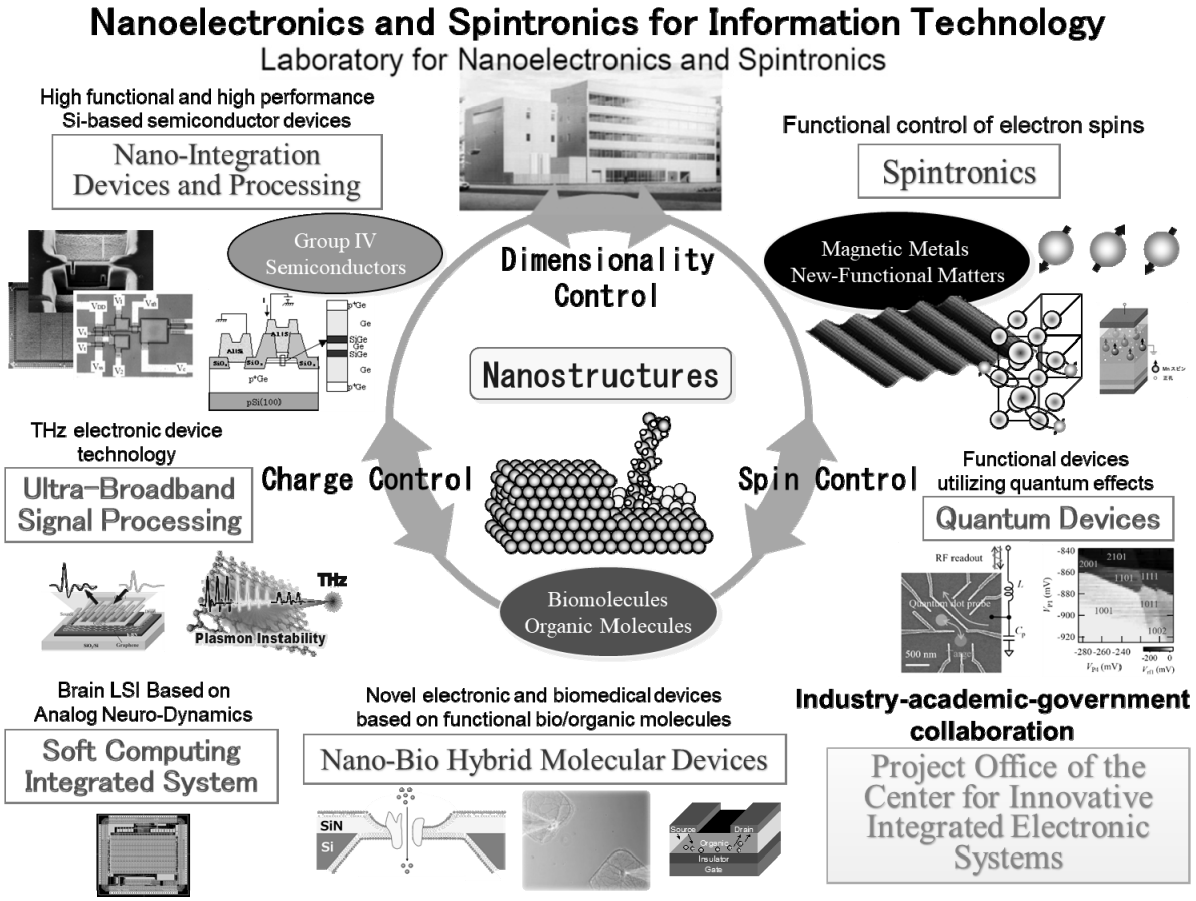
[Papers]

[1] N. Onizawa, et al., "Fast-Converging Simulated Annealing for Ising Models Based on Integral Stochastic Computing," IEEE Trans. on Neural Networks and Learning Systems, 2022 (to appear).
[2] N. Onizawa and T. Hanyu, "CMOS Invertible Logic: Bidirectional Operation Based on Probabilistic Device Model and Stochastic Computing," IEEE Nanotechnology Magazine, vol. 16, issue 1, pp. 33-46, Feb. 2022.
[3] M. Natsui, et al., "Dual-Port SOT- MRAM Achieving 90-MHz Read and 60-MHz Write Operations under Field-Assistance -Free Condition" IEEE Journal of Solid-State Circuits, vol. 56, no. 4, pp.1116-1128, April 2021.

Laboratory for Nanoelectronics and Spintronics

The Laboratory for Nanoelectronics and Spintronics of the Research Institute of Electrical Communication (RIEC) was established in April of 2004. Its purpose is to develop and establish the science and technology of nanoelectronics and spintronics for information technology. Utilizing the facilities installed in the Nanoelectronics-and-Spintronics building and under collaboration between RIEC and related laboratories of the Graduate Schools of Engineering, Information Sciences, Biomedical Engineering, of Tohoku University, R&D on nanotechnologies of materials and devices in Nanoelectronics and Spintronics are continued extensively. Furthermore, nation-wide and world-wide collaboration research projects are conducted to build a systematic database in electrical communication research.

The Laboratory for Nanoelectronics and Spintronics mainly consists of laboratories of Nano-Integration Devices and Processing, Spintronics, and Nano-Bio Hybrid Molecular Devices; together with the project office of the Center for Innovative Integrated Electronic Systems, and the groups of Ultra-Broadband Signal Processing, Soft Computing Integrated System and Quantum Devices. These groups cooperatively carry out the research aimed at establishing a world-wide Center of Excellence (COE) in the research area of nanoelectronics and spintronics.



Highlights of our research activities in 2021 are shown below.

Nano Integration

● Nano-Integration Devices and Processing (S. Sato, M. Sakuraba, and H. Yamamoto)

(1) Toward the development of neuromorphic computation hardware, we fabricated a recurrent neural network LSI composed of spiking neurons that can reproduce various neuron pulses with ultra-low power consumption. We confirmed by electrical measurements that our analog MOS circuit correctly operated in the weak inversion region and that the network showed various responses depending on input signal.

(2) Low-energy plasma chemical vapor deposition method enables the formation of Si nitride film with a composition close to stoichiometric ratio, and it is experimentally shown that a nanometer-thick Si nitride film under the thermally oxidized SiO2 dielectric film can suppress thermal oxidation of the substrate surface.

(3) Toward the development of a dedicated hardware for reinforcement learning, we investigated the relationship between the bit-length of floating-point operations and the learning performance of the Q-learning algorithm.

● Soft Computing Integrated System (Y. Horio)

We are working on a novel high-performance, highly-efficient, flexible, and robust brain-inspired brainmorphic computer hardware system, in particular, through physical complex-networked dynamical process using an analog VLSI as a core component. Results of this year are summarized as follows:

(1) We implemented a proof-of-concept chip for a cyclic-updating chaotic neural network reservoir (CNNR) integrated circuit using TSV/μbump three-dimensional stacked IC technology. The experimental results from the chip confirmed the validity and efficiency of the proposed technique. We also developed a full circuit level emulator based on the measurement results to evaluate learning CNNR networks.

(2) We improved our mathematical model of neuron-like and synapse-like spintronics devices to be applicable to integrated circuit and learning neural network designs. Some novel spintronics-based neural networks were proposed using the improved model.

(3) We proposed six online learning algorithms for real-time additional learning of reservoir neural networks. Performances of these algorithms were compared through simulations on discrete word recognition tasks.

(4) We clarified the effects of local memory (refractoriness) inside the neuron, and the maximum gain of the neuronal output function in the CNNR on word recognition performance through simulations. As a result, we found that suitable exponential decay of the internal state improves the performance.

Spintronics and Information Technology

● Spintronics (S. Fukami)

Our research activities focus on realizing low-power functional spintronic devices. The outcomes in the last fiscal year are as follows: (1) Summarizing physical properties and

potential materials for qubit applications with spin centers, (2) proposing double-free-layer stochastic magnetic tunnel junction for probabilistic bit applications and clarifying the physical mechanism governing the time-domain and time-averaged properties, (3) discovering a persistent rotation of chiral-spin structure in non-collinear antiferromagnet driven by current-induced spin-orbit torque, (4) demonstrating the energy harvesting of Wi-Fi band signal using series connected spintronic oscillators, (5) elucidating the critical factors that govern the topological properties of non-collinear antiferromagnetic Mn3Sn thin film through a systematic measurement of the crystalline structure, magnetic properties and magnetotransport properties, (6) revealing a missing factor in the analysis of current-induced hysteresis loop measurement that is used to quantify the Dzyaloshinskii-Moriya interaction, (7) clarifying the physical mechanism governing the time-averaged response of the stochastic magnetic tunnel junction with respect to magnetic field and current, (8) demonstrating a nonvolatile control of oscillation properties in an artificial structure consisting of spin Hall nano-oscillators as an artificial neuron and memristors as an artificial synapse, (9) establishing a device technology to extend nonvolatile magnetic tunnel junction to angstrom semiconductor generation while keeping high performance, and (10) demonstrating Boltzmann machine learning using a probabilistic bits with stochastic magnetic tunnel junctions.

● Ultra-Broadband Signal Processing (T. Otsuji and A. Satou)

The goal of our research is to explore the terahertz frequency range by creating novel integrated electron devices and circuit systems. III-V- and graphene-based active plasmonic heterostructures for creating new types of terahertz lasers and ultrafast transistors are major concerns. By making full use of these world-leading device/circuit technologies, we are developing future ultra-broadband wireless communication systems as well as spectroscopic/imaging systems for safety and security. The followings are the major achievements in 2021FSY.

1. Creation of graphene-based current-injection terahertz lasers

Graphene, a monolayer sheet of honeycomb carbon crystal, is expected to break through the limit on conventional device operating speed/frequency performances. Towards the creation of novel current-injection graphene THz lasers, we developed a graphene laser-transistor featured with our original asymmetric dual-grating gates demonstrating coherent amplification of THz radiation with the maximal gain of 9% at room temperature promoted by graphene plasmon instabilities driven by dc-channel current flow (Press-released on July 2020).

2. Development of plasmonic terahertz detectors

For future ultrahigh-speed wireless communications, we have developed plasmonic terahertz detectors with original metallic diffraction-grating structures, which utilize hydrodynamic nonlinearities of two-dimensional plasmons in the channels of InGaAs high-electron-mobility transistors (InGaAs-HEMTs). This fiscal year, we demonstrated that

the "3D rectification effect", where the diode current nonlinearity associated with the electron tunneling is superimposed onto the plasmonic hydrodynamic nonlinearities, can take place by applying a positive gate bias voltage in the gate-readout configuration of the photovoltage and succeeded in drastic enhancement of the detector responsivity by one order of magnitude.

● **Quantum Devices (T. Otsuka)**

We are exploring interesting properties of solid-state nanostructures utilizing precise and high-speed electric measurement and control techniques. We are also developing materials and devices using nanostructures. Our research activities in FY 2021 are the following.

(1) We developed electronic measurement and control methods of local electronic states in nanostructures utilizing semiconductor quantum dots. We improved the methods with high-frequency techniques and data informatics approaches.

(2) We measured local electronic and spin states in nanostructures utilizing sensitive electronic measurement techniques. We revealed the detail of local electronic states in quantum dot devices and new materials.

(3) We studied semiconductor quantum bits for future quantum information processing. We worked on quantum bit operations and readout and developed techniques for scale-up of quantum systems.

Nano-Bio Hybrid Molecular Devices

● **Nano-Bio Molecular Devices (A. Hirano-Iwata)**

Our research activities focus on development of sophisticated molecular-scale devices through the combination of well-established microfabrication techniques and various soft materials, such as biomaterials and organic materials.

(1) We developed a new measurement system for artificial lipid bilayer membranes, in which a lateral voltage was introduced as a new input in addition to the traditional transmembrane voltage. We demonstrated that the new system could effectively modulate the ion-channel activity and the performance of hybrid devices based on fullerene-doped bilayer membranes.

(2) In collaboration with a member of the newly launched Grant-in-Aid for Transformative Research Area (B) “Multicellular Neurobiocomputing” (MEXT KAKENHI), we developed a novel microelectrode technology to deliver localized stimulation to cultured neuronal networks grown on microfabricated substrates.

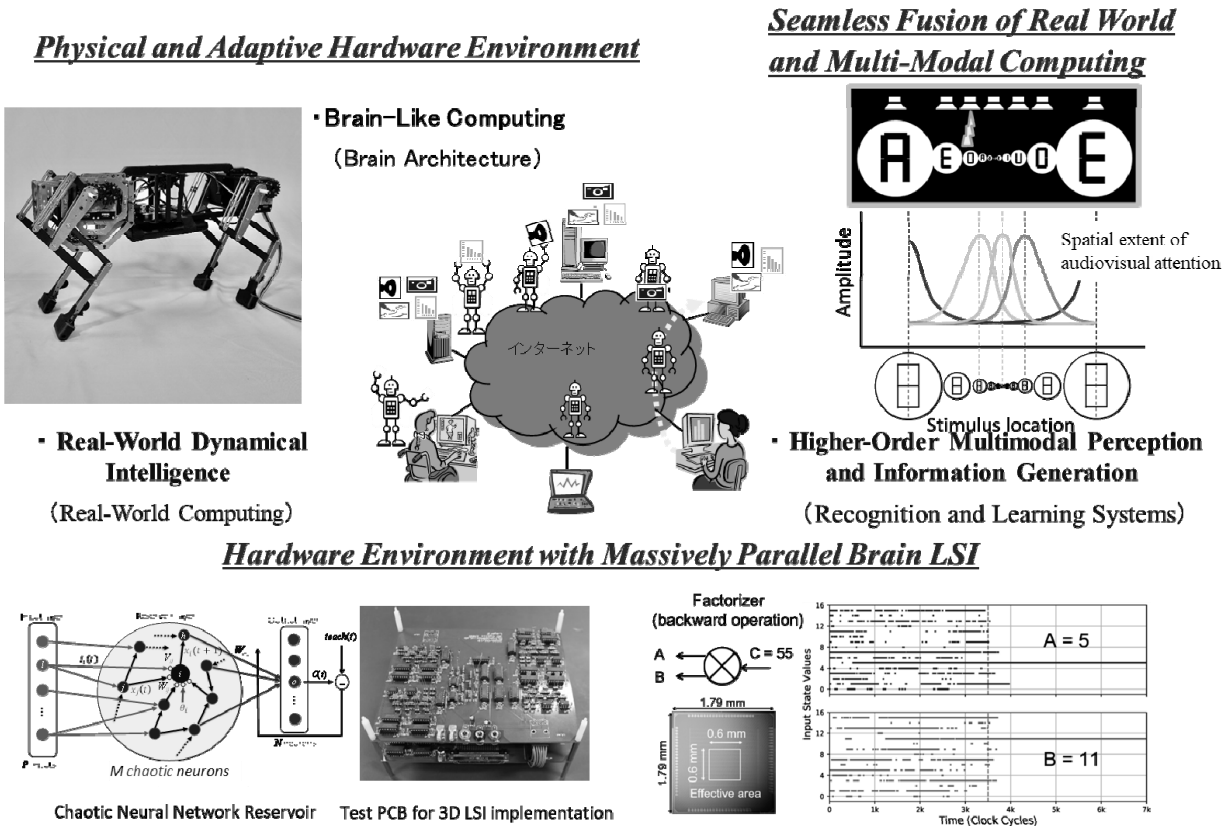
(3) We developed a TiO_2 nanotube-based gas sensor for precisely detecting trace amounts of CO in a gas mixture. We also confirmed the bactericidal activity of nanobubbles generated using porous alumina films.

Research Targets and Activities of Laboratory for Brainware Systems

The Laboratory for Brainware Systems of the Research Institute of Electrical Communication was established in 2004 and renewed in 2014. Its purpose is to contribute to the research and development of advanced information science and technology for Brainware systems which realize a seamless fusion of the changeable and complex real world and the cyber space.

We aim at establishing scientific and technological foundations and at exploring human-like brainware computing applications for Adaptive Cognition and Action Systems Division (Recognition and Learning Systems Group), Autonomous Decentralized Control Systems Division (Real-World Computing Group), Brainware LSI Systems Division (New Paradigm VLSI System Group and Soft Computing Integrated System Group), and Brain Architecture Division. The Laboratory for Brainware Systems consists of the above four divisions which cooperatively carry out the research. At the same time, they serve as a laboratory for nation-wide cooperative research in the field of Brainware systems.

The technology developed in the Laboratory is expected to enhance the research carried out in the four Divisions of the Institute, and the research conducted in the Divisions, in turn, is expected to provide scientific basis for the information technology developed in the Laboratory.



[Research Target]

The goal of this facility is to develop fundamental technologies and their applications that will lead the world to the next-generation information system that seamlessly integrates the cyber-physical world and the ever-changing real world. In order to realize this goal, each laboratory participating in this facility has set the following individual goals and promotes research activities as follows:

Real-World Computing Section: Animals exhibit adaptive locomotion under unpredictable and unstructured environments by coordinating their large number of bodily degrees of freedom in real time. We aim to understand the design principle of such adaptive locomotion by focusing on autonomous decentralized control wherein macroscopic behaviors emerge from local interactions among each individual components. Moreover, we aim to develop artificial agents (*e.g.* robots) that

function like animals by implementing the obtained design principle.

New Paradigm VLSI System Section: Rapid progress in recent deep submicron regime has led the capability to realize giga-scaled embedded systems on a chip (SoC), while performance degradation of SoCs due to wiring complexity, power dissipation and device-characteristic variation are increasingly getting serious problems in the recent VLSI chip. Our research activity is to solve the above problems primarily by the following two ways: the use of logic-in-memory architecture based on nonvolatile logic, and the use of asynchronous data-transfer schemes based on multiple-valued current-mode logic, which would open up a novel VLSI chip paradigm, called a "new-paradigm VLSI system."

Recognition and Learning Systems Section: Humans can perform various actions based on the recognition of the outside world that is constructed through multiple sensory inputs such as vision and touch, even though they frequently move their own body parts in the environment. Here we investigate the adaptive-process and functions of the human cognitive system for action through psychophysical experiments. On the basis of the experimental evidence, we aim to create computational models of the recognition and learning processes in the human brain.

Soft Computing Integrated System Section: We are working on a novel high-performance, highly-efficient, flexible, and robust brain-inspired brainmorphic computer hardware system, in particular, through physical complex-networked dynamical process using an analog VLSI as a core component. Toward the final goal, we are developing integrated circuit and device technologies suitable for the brainmorphic computer systems. We further intend to realize an autonomous brain-inspired computer with a sense of self and consciousness based on dynamic and complex changes in spatiotemporal network state and structure.

[Research Activities]

Aiming at the seamless integration of the cyber-physical world and the real world, which is the goal of Laboratory of Brainware Systems, the following research results were obtained. In particular, the following research results in fiscal year 2021 are an important step towards the goal as:

--Real-World Computing Section demonstrates " Spontaneous Gait Transitions of Sprawling Quadruped Locomotion by Sensory-Driven Body–Limb Coordination Mechanisms" reported in Frontiers in Neurorobotics.
https://www.frontiersin.org/articles/10.3389/fnbot.2021.645731/full

--New Paradigm VLSI System Section has succeeded in demonstrating that the problem size solved by our stochastic-logic-based method in the combinatorial optimization problem is about 16 times larger than that of a typical quantum annealer, called D-wave machine .
https://doi.org/10.1109/TNNLS.2022.3159713
https://doi.org/10.1109/MNANO.2021.3126094

--Recognition and Learning Systems Section reported "Quali-informatics in the society with yotta scale data" in IEEE International Symposium on Circuits and Systems (ISCAS), 1-4 (2021)
https://ieeexplore.ieee.org/abstract/document/9401161

--Soft Computing Integrated System Section develops "Preliminary experimental results of a stacked 3D cyclic chaotic neural network reservoir integrated circuit" reported in Nonlinear Theory and Its Applications, IEICE.
https://www.jstage.jst.go.jp/article/nolta/13/2/13_306/_article/-char/en

The more detailed research results of each section (laboratory) are shown as follows:

Real-World Computing Section:
(refer to Real-World Computing Laboratory in Human Information Systems Division)

New Paradigm VLSI System Section:
(refer to New Paradigm VLSI System Laboratory in Systems & Software Division)

Recognition and Learning Systems Section:
(refer to Visual Cognition and Systems Laboratory in Human Information Systems Division)
(refer to Advanced Acoustic Information Systems Laboratory in Human Information Systems Division)

Soft Computing Integrated System Section:
(refer to Soft Computing Integrated System Laboratory in Systems & Software Division)

Recognition and learning systems laboratory

Understanding the human recognition and learning systems

(Visual Cognition and Systems, Satoshi Shioiri, Professor)
(Advanced Acoustic Information Systems, Shuichi Sakamoto, Professor)

[Research Target and Activities]

To create computational models of the process that the human brain integrates multiple sensory inputs from the outside world, we are investigating the visual and auditory functions in the human brain for implementing these functions in hardware under biologically plausible settings. Our approaches include psychophysics, brain wave measurements, and computer simulations.

This year, first, we investigated method of value estimated of images based on human preference judgments. Accumulation of information is essential for human knowledge production, and information technology has accelerated the speed of data accumulation. The increase in quantity of information with high speed does not promise high quality knowledge production and possibly does cause problems. One big problem is lack of storage for such big data. Another critical problem in information usage is information overload, that is, deterioration of productivity by too much information. Decision accuracy decrease with amount of information beyond a certain point while it increases at the beginning. We introduce an approach for solution of these problems with an example of research along the approach.

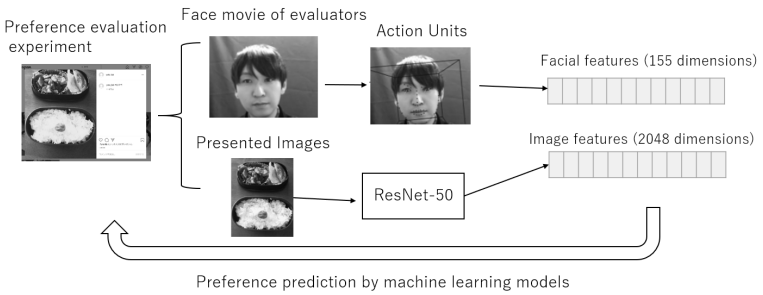


Figure. Schematic diagram of the image preference evaluation experiment and the analysis of image preference estimation.

Second, we investigated how humans extract target sounds from distractor sounds by using auditory selective attention. We have especially focused on the effect of auditory selective attention in the spatial domain and measured the shape of the spatial window of auditory spatial attention in the horizontal plane. The experiment results revealed that the observed spatial pattern of the auditory selective attention depends on the direction. The shape of the spatial window of the auditory selective attention was broader in the side direction than that in the frontal direction. The results imply a relationship between the shapes of the spatial window of auditory selective attention and the accuracy of sound localization.

[Staff]

Professor: Satoshi Shioiri, Ph.D.
Professor: Shuichi Sakamoto, Ph.D.

[Papers]

[1] 1. S. Shioiri, T. Sasada, R. Nishikawa, Visual attention around a hand location localized by proprioceptive information. *Cereb Cortex Commun* **3**, tgac005 (2022).
[2] 3. S. Shioiri, K. Matsumiya, C. H. Tseng, Contribution of the slow motion mechanism to global motion revealed by an MAE technique. *Scientific reports* **11**, 3995 (2021).
[3] S. Tomimatsu, S. Sakamoto, T. Kawase, & M. Chait, "Directional dependency of auditory spatial attention in the horizontal plane," *IEICE Technical Report*, SP2021-37, 66-70, 2021. (in Japanese)

Research Center for 21st Century Information Technology

Research and Development of the IT-Based Practical Technology by the Industry-Academia-Government Collaboration

[Research Target and Activities]

The purpose of the IT-21 center is development of practical technologies for IT based on the advanced technologies of RIEC with the partnership among Industry, Government and University. The term of development is limited less than 5 years. The projects are planned on matching with both basic technologies in the University and application in the Industry. Combination of the technologies of the University and Industry makes practical technologies with availability for the commercial products. The center actively accelerates to obtain the intellectual properties generated from the development of practical technology to the Industry. Last year, the center was reformed and two divisions are newly established. One is "Interdisciplinary Collaboration Research Division" and it consists of two projects, "Research project of human value estimation of multimodal information based on informatics paradigm to manage both quality and value" and "Research project of spintronics/CMOS-hybrid brain-inspired integrated system". Another is "Challenging and Exploratory Research Division" and it consists of two projects, "Interactive drone content for entertainment / wildlife symbiosis" and "Wireless IoT Technology for a safe & secure mediciation management system". Former "Technology Development Division" was renamed to "Industry-Academia-Government-Collaboration Research and Development Division" and it consists of one group, "Wireless ICT platform project". Presently, following projects are carried out in this group.

・R&D on Adaptive Media Access Control for Increasing the Capacity of Wireless IoT Devices in Factory Sites

From 2019, the mobile wireless technology group has started a project "R&D on Adaptive Media Access Control for Increasing the Capacity of Wireless IoT Devices in Factory Sites" supported by the Ministry of Internal Affairs and Communications. In this project, we have successfully developed a 5GHz-band simplified beam forming wireless IoT communication system using Wi-Fi backscatter and have completed this project.

・R&D Project for Enhancement of the Bases for Post-5G Information and Communication Systems

From 2020, the group has started a new project "R&D Project for Enhancement of the Bases for Post-5G Information and Communication Systems" supported by the supported by the New Energy and Industrial Technology Development Organization (NEDO). In this project, we are going to develop Silicon(Si) Radio Frequency (RF)IC and 1-bit delta-sigma modulation direct digital RF transmitter for post 5G base stations

[Staff]

Director: Noriharu Suematsu, Professor

Industry-Academia-Government-Collaboration Research and Development Division
(Wireless ICT platform project)

Noriharu Suematsu, Leader, Professor
Takashi Shiba, Specially Appointed Professor
Suguru Kameda, Visiting Professor
Yasunori Suzuki, Visiting Professor
Kenichi Maruhashi, Visiting Professor
Mizuki Motoyoshi, Visiting Associate Professor
Takashi Mehata, Visiting Associate Professor

Interdisciplinary Collaboration Research Division

Satoshi Shioiri, Project Leader, Professor
Takahiro Hanyu, Project Leader, Professor

Challenging and Exploratory Research Division

Yoshifumi Kitamura, Project Leader, Professor
Noriharu Suematsu, Project Leader, Professor

IT21 Center Industry-Academia-Government-Collaboration Research and Development Division, Wireless ICT Platform Project

Dependable Air

Noriharu Suematsu, Professor (Project Leader)
Takashi Shiba, Specially Appointed Professor

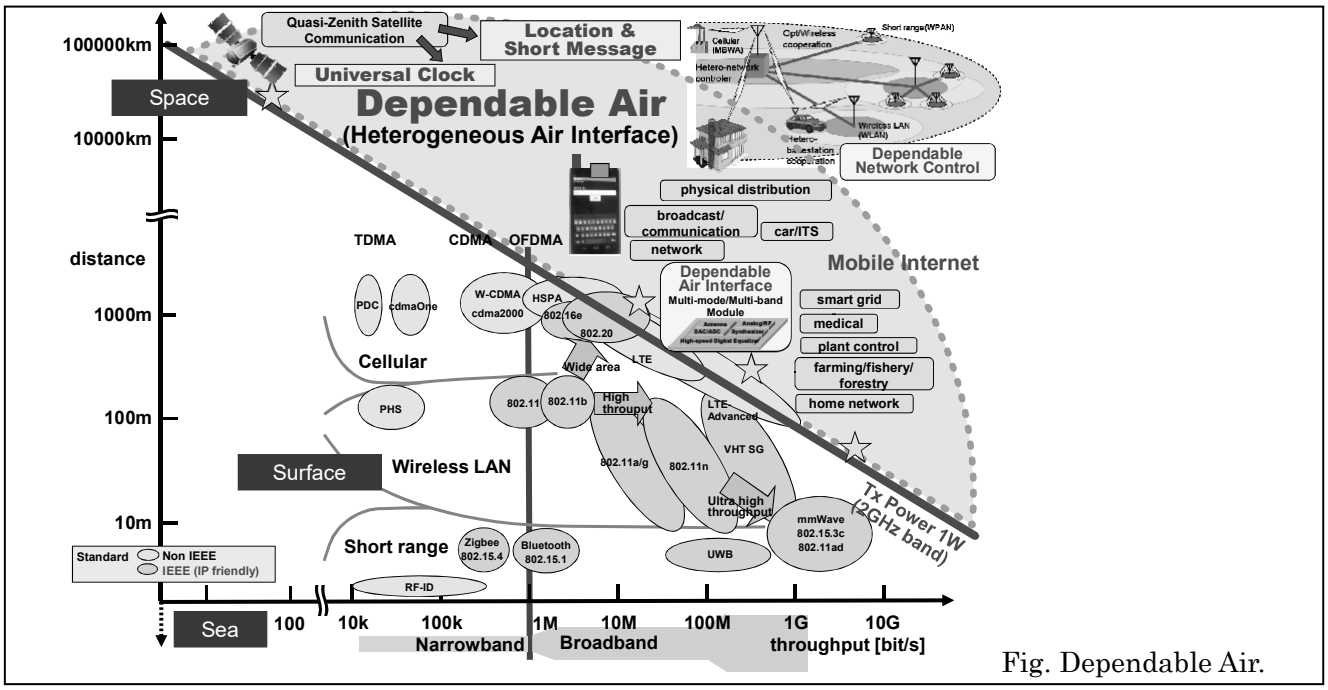


Fig. Dependable Air.

[Research Target and Activities]

Mobile wireless communication technology is one of the significant communication technologies that support the Information and Communication Technology (ICT) society, connected with the high-speed backbone network using optical fiber. Evolution of the mobile wireless communication technology in Japan is indispensable to keep the leadership in this technology area in the world. The mobile wireless technology group has been proposing the concept of "Dependable Air," which is a heterogeneous and highly-reliable wireless network. The Dependable Air is able to work even in the event of a big disaster.

After finishing the set of R&D projects related to disaster relief, the group has started the project named "wireless ICT platform" which is the digital rich transceiver hardware technologies suitable for Dependable Air, software radio and wireless Internet of Things (IoT) in B5G/6G era. The group finished a R&D project "R&D on Technologies to Densely and Efficiently Utilize Radio Resources of Unlicensed Bands in Dedicated Areas" supported by the Ministry of Internal Affairs and Communications (MIC) from FY2017 to FY2020. The group proceeded R&D project "R&D on Adaptive Media Access Control for Increasing the Capacity of Wireless IoT Devices in Factory Sites" supported by MIC from FY2019. The group also started "Research and Development Project for Enhancement of the Bases for Post-5G Information and Communication Systems" supported by the New Energy and Industrial Technology Development Organization (NEDO) from FY 2020.

[Staff]

Professor: Noriharu Suematsu, Ph.D
Specially Appointed Professor: Takashi Shiba, Ph.D

Contact to Professor SUEMATSU Noriharu : noriharu.suematsu.a3@tohoku.ac.jp

[Papers]

[1] N. Suematsu, K. Edamatsu, T. Machii, J. Temga, M. Motoyoshi, S. Kameda, T. Shiba, " 5 GHz-Band Simplified Beam Forming Wireless IoT Communication Using Wi-Fi Backscatter," IEICE Transactions on Electronics, Vol. J105-C, No. 1, pp. 2-10, Sep. 2021.

[2] T. Shiba, T. Furuichi, M. Motoyoshi, S. Kameda, N. Suematsu, "A Spectrum Regeneration and Demodulation Method for Multiple Direct Undersampled Real Signals," IEICE Transactions on Communications, Vol. E104-B, No. 10, pp.1260-1267, Oct. 2021.

[3] N. Suematsu, K. Edamatsu, T. Machii, M. Motoyoshi, S. Kameda, T. Shiba, "5GHz Simplified Beam Forming Wireless IoT Communication using Wi-Fi Backscatter," 2021 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), Aug. 2021.

[4] J. Temga, M. Motoyoshi, T. Shiba, N. Suematsu, "A 5.5GHz Band 2-D Beamforming Network Using Broadside Coupled Stripline Structure," 2021 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), Aug. 2021.

[5] J. Temga, T. Machii, T. Shiba, N. Suematsu, "28GHz-Band 2x2 Patch Antenna Module Vertically Integrated with a Compact 2-D BFN in Broadside Coupled Stripline Structure," 2021 IEEE Asia-Pacific Microwave Conference (APMC), pp.73-75, Nov. 2021.

[6] J.Temga, M. Motoyoshi, T. Shiba, N. Suematsu, "A 5.5GHz-Band 2x2 Array Antennas Module Based on Compact 2-D Beamforming Network in Broadside Coupled Stripline," 2022 16th European Conference on Antennas and Propagation (EuCAP), Mar. 2022.

Interdisciplinary Collaboration Research Division

Research project of human value estimation of multimodal information based on informatics paradigm to manage both quality

Satoshi Shioiri, Dr. Professor
Nobuyuki Sakai, Dr. Professor

[Research Target and Activities]

Human facial expression is related to emotion, perception, cognition, decision and so on. We attempted to predict preference judgments of images from facial expression while evaluating images using machine learning methods. We performed preference estimation for images and compared performance of three models, and found that facial expression proves useful information for estimating human judgments.

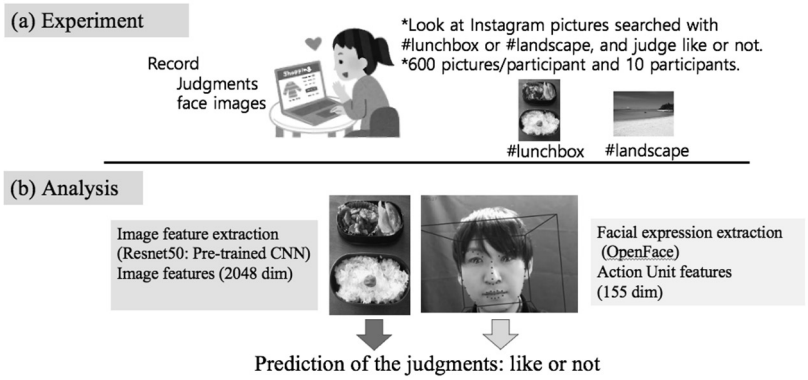


Fig. 1 Estimation of human preference judgments from facial expressions and image features.
(a) Subjective judgments for preference of images evaluation.
(b) Analyses of facial expression and image features for prediction of the preference judgements.

[Staff]

Professor : Satoshi Shioiri, Dr.
Professor : Nobuyuki Sakai, Dr.
Assistant Professor : Kosuke Yamamoto, Dr.

[Profile]

Satoshi SHIOIRI Professor Shioiri graduated Tokyo Institute of Technology and received Dr. Eng in 1986. In 2005, he joined Tohoku University and he has been a professor of Research Institute of Electrical Communication of Tohoku University since then.

Nobuyuki Sakai graduated from Graduate School of Human Sciences, Osaka University in 1998. Then he worked at Hiroshima Shudo University and National Institute of Advanced and Industrial Science and Technology (AIST) , Kobe Shoin Women's University. He, then, moved to Sendai in October 2011, and he is a professor of Graduate School of Arts and Letters of Tohoku University now.

[Papers]

[1] T. Hasegawa and N. Sakai, "Comparing Meal Satisfaction Based on Different Types of Tableware: An Experimental Study of Japanese Cuisine Culture", Foods, 10, 1546, 2021
[2] A. Saita, K. Yamamoto, R. Takei, H. Washio, S. Shioiri, N. Sakai "Crispness, the Key for the Palatability of "Kakinotane": A Sensory Study with Onomatopoeic Words", Foods, 10, 1724, 2021
[3] S Shioiri, Y Sato, Y Horaguchi, H Muraoka, M Nihei, "Quali-informatics in the society with yotta scale data", 2021 IEEE International Symposium on Circuits and Systems (ISCAS), 1-4, 2021

Exploratory Research Division

Interactive Drone Content for Entertainment / Wildlife Symbiosis

Yoshifumi KITAMURA, Professor

[Research Target and Activities]

This project aims to develop core technologies of interactive drone content for real industrial use including entertainment and wildlife symbiosis, through close industry/academia/government cooperation. It is expected to support continuous development of drone technologies through this innovation, and produce new industry and services in response to societal needs.
The followings are current research projects:
(1) Development of intuitive user interface for a drone pilot
(2) Development of crow-type-drone to communicate with crows.

[Staff]

Professor: Yoshifumi Kitamura, Dr.

[Profile]

Yoshifumi Kitamura: Since 2010, Yoshifumi Kitamura has been Professor in the Research Institute of Electrical Communication, Tohoku University. Prior to arriving at Tohoku, he was an Associate Professor at Graduate School of Engineering, and Graduate School of Information Science and Technology, Osaka University. While working at ATR Communication Systems Research Laboratories, he focused on sophisticated user interfaces in virtual environments. His first formal appointment was in the Information Systems Research Center Canon Inc., where he was involved in research on artificial intelligence, image processing, computer vision, and 3D data processing. His formal education was obtained at Osaka University, B.Sc (1985); M.Sc. (1987); and Ph.D. (1996).

[Papers]

[1] Linfeng Chen, Kazuki Takashima, Kazuyuki Fujita, Yoshifumi Kitamura, PinpointFly: An Egocentric Position-control Drone Interface using Mobile AR, Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI), Article 150,13 pages, May 2021.

IT21 Center
Exploratory Research Division

Wireless IoT Technology for a Safe & Secure Medication Management System

Safe & Secure Medication Management System using Wireless IoT Technology

Noriharu Suematsu, Professor (Project Leader)
Takahiro Hanyu, Professor
Kazushi Ishiyama, Professor
Naofumi Homma, Professor
Qiang Chen, Professor
Suguru Kameda, Visiting Professor (Hiroshima University)
Mizuki Motoyoshi, Visiting Associate Professor (Shizuoka Institute of Science and Technology)

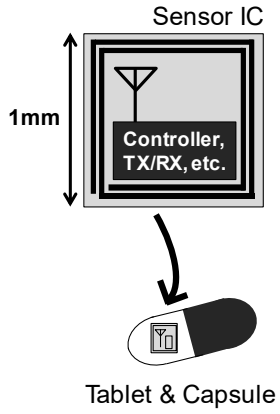


Fig.1 Battery-less tablet-pasting-type sensor

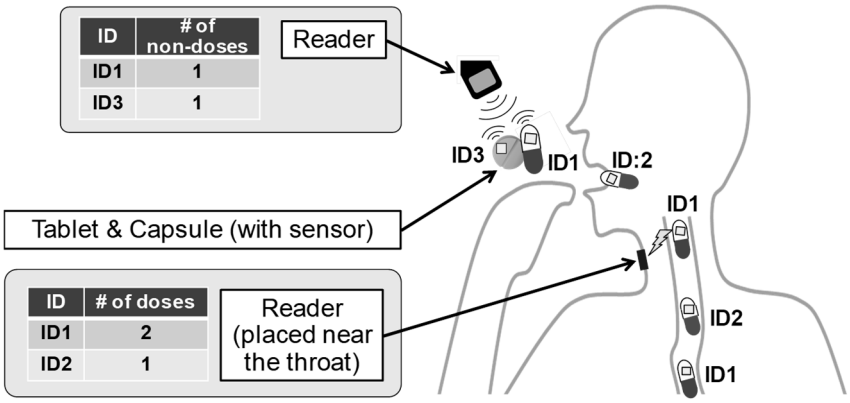


Fig.2 Safe medication management system

[Research Target and Activities]

Medical costs that continue to increase with progress in aging society and medical advances are serious social problems on the worldwide scale. In order to reduce medical expenses, it is indispensable to construct a medication management system that enables inventory control and confirmation of ingestion.

This division conducts exploratory research on establishing a safe medication management system using wireless IoT technology. The goal of this research is the realization and practical implementation of system construction that allows patients to take medication management just by taking tablet-type medicine. In this research, we are now studying for the battery-less tablet-pasting-type sensor by applying wireless IoT technology.

In this year, we evaluated low power ASK transmitter using SOI-process with high impedance substrate to increase the efficiency of antenna. In addition, the reflector under the loop antenna was employed to increase the radiated power toward the chip surface. The transmitter was evaluated and compared to a transmitter using bulk-CMOS process under the same power consumption and communication distance conditions. The power output from the circuit core through the source follower type buffer amplifier increase by 4 dB compared to the circuit using bulk CMOS. Moreover the radiated power increased by 9 dB when the proposed antenna is used. The proposed antenna is expected to extend the communication distance to 27 cm.

Management Office for Safety and Health

Realizing and Maintaining a Safe and Comfortable Environment to Support Research

[Research Target and Activities]

Safety and health seminar (Online)

High pressure gas safety seminar (Online)

1. Outline of the Management Office for Safety and Health

The Management Office for Safety and Health is established to maintain the safety and health of students and staff working at the institute. The use of chemicals, high-pressure gas and radiation in research activities at the institute entails many risks. The Management Office for Safety and Health provides support for safety and health management in research laboratories, experimental facilities and the Fundamental Technology Center through various activities to ensure safe and smooth research activities within the institute.

2. Activities by the Management Office for Safety and Health

For the actual management of safety and health at the office, the Safety and Health Committee first presents the basic policies of safety management at the institute, and the Management Office for Safety and Health then plans and executes activities based on them. At the institute, laboratories and other individual sections are highly independent of each other; unlike a general corporate organization, top-down safety management is not suitable and measures appropriate for independent sections need to be taken. Various considerations are also necessary for students, researchers, and other members engaged in research activities as well as faculty staff. At this institute, extremely hazardous materials and facilities are used, including chemicals, high-pressure gas, and X-ray devices. Since there is also a clean room and other special workplaces, safety management should be extended by considering them. In these circumstances, the Management Office for Safety and Health will monitor situations and characteristics in each section at the institute, plan and recommend practical management methods and improvement measures, and support their implementation for the efficient and effective management of safety and health. The main activities in this fiscal year are as follows:

- ○ Holding safety and health seminar and high-pressure gas seminar for staff and students at the institute
- ○ Inspection of and assistance in improving the safety and health management system and working environment within the institute
- ○ Holding first aid training course
- ○ Investigation of laws related to safety and health and collection of information regarding safety and health management
- ○ Providing advice and information to safety and health personnel in each department

[Staff]

Manager: Kazushi Ishiyama, Professor

Deputy Manager: Shigeo Sato, Professor

Nobuyuki Sato, Assistant Professor

Maho Abe, Technical Staff　　Haruka Takahashi, Clerk

Flexible Information System Center

Development and Management of Flexible Information System

[Summary and Role of the Flexible Information System Center]

The existing information systems are inflexible, meaning that they only provide processing functions predetermined in their design phase. The objective of this center is to introduce, operate, and maintain information networks and systems to support research activities in RIEC, based on the concept of flexible information processing that reflects human intentions and the environment.

Figure 1 RIEC network system

Moreover, utilizing know-how obtained through practical experiences of the information networks and systems, this center designs and constructs the state-of-the-art systems for advanced organization, utilization, management and operation, and dispatch of scientific information.

1. Information collection, organization, dispatching, utilization, and research support environment.
2. Advanced maintenance, management, and operation of the network.
3. Technical support for information networks and systems in the institute.

[Status Report of the Flexible Information System Center]

Management and operation of the RIEC network information system.
At the Flexible Information System Center, we manage and operate the server system and the information network underlying the academic research conducted throughout the Research Institute of Electronic Communication (hereafter RIEC).

・Maintaining and monitoring the server and network hardware.
・Responding to information security crises.
・Advising and answering problems on the use of network services raised by individual research groups.
・Conducting seminars to network managers of research groups.
・Managing the information system accounts.
・Constructing and renewing the official RIEC website.
・Developing and publishing videos containing the events and conferences associated with RIEC activities.
・Improving on the security measures of mobile devices checked out of the RIEC premises.
・Operating the system with backup power sources under scheduled power shutdowns.

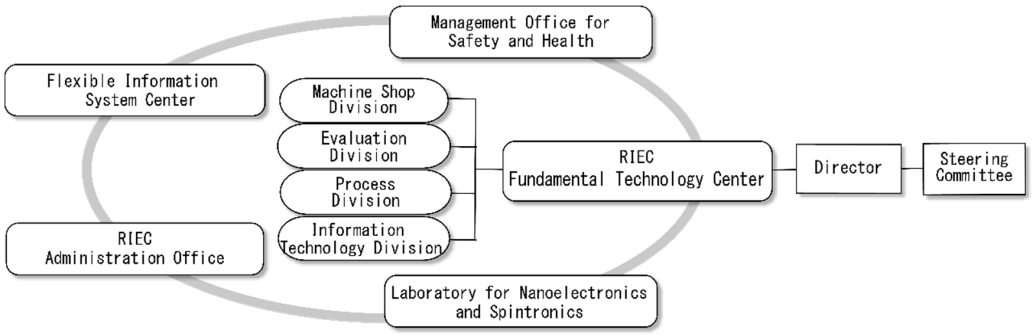
[Staff]

(1) Steering Committee
Professors: Go Hasegawa, Dr., Masafumi Shirai, Dr., Takuo Suganuma, Dr., Hiroshi Yasaka, Dr., Akio Ishiguro, Dr.

(2) Staff
Director (Professor): Go Hasegawa, Dr.
Professor*: Takuo Suganuma, Dr.
Associate Professor*: Gen Kitagata, Dr.
Technical Official: Kenji Ota
Technical Official*:Yuko Maruyama
Technical Support Member: Mutsumi Shuto, Riho Ooizumi

Fundamental Technology Center

Supporting research with high-level specialized knowledge and technology



Overview of the Fundamental Technology Center

[Research Target and Activities]

The Fundamental Technology Center provides a wide range of technical support for research and development through four divisions: Machine Shop Division, Evaluation Division, Process Division, and Information Technology Division. The following is a summary of the activities of the divisions of the Fundamental Technology Center for the current year.

1. Machine Shop Division

Following requests from researchers, the Machine Shop Division supplied 103 machining products. About 8% of the requests were from outside the institute.

2. Evaluation Division

23 laboratories utilized the evaluation and measurement apparatuses for shared usage (the utilization time was 2,048 hours). Technical assistance on the use of liquid helium was provided for 3 laboratories, and 58 liters of liquid nitrogen were supplied. In cooperation with the administration and the management offices for safety and health, this division also engaged in safety maintenance of the institute.

3. Process Division

In cooperation with the technical office, a section of the Laboratory for Nanoelectronics and Spintronics, 271 Electron-beam lithography products, 27 photomasks and 5 focused-ion-beam micro products were supplied. Technical supports and maintenance were provided for operating the clean rooms of the Laboratory for Nanoelectronics and Spintronics.

4. Information Technology Division

This division operated the in-house network at the institute and maintained shared-use-information-equipment, in cooperation with the Flexible Information System Center. This division also engaged in the contracting aspects of collaborative research based on intellectual property rights and gave advice to researchers who tried to apply for the grant of patents.

[Staff]

Director (Professor): Shigeo SATO.
Assistant Professor: Nobuyuki SATO.
Technical Officials: Tamotsu SUENAGA, Kento ABE, Yasuaki MAEDA, Kana SEKIYA, Maho ABE, Takenori TANNO, Hiroyuki YAGYU, Iori MORITA, Rikima ONO, Michimasa MUSHA, Yuko MARUYAMA, Kenji OHTA, Koichi SHOJI.

Ad-hoc research groups

Taking advantage of the wide range of expertise in the institute, ad-hoc research groups are formed outside of the formal organizational structure to investigate challenging exploratory topics and needs-based, cutting-edge subjects.

[Group of multimodal attention]

Selecting information obtained through sensory organs by attention is inevitable to live the complicated world with dynamic changes. A number of studies have investigated the mechanisms of attention related to cognitive processes, and little is known about attention effect on action. This research group investigates representation of space in the brain, which expresses the outside space based on multiple sensory information. We hypothesize that attention in the multi-sensory spatial representation is crucial to select action. We investigated interaction between visual and auditory attention and found the effect of visual attention on auditory perception. We also started to investigate method to measure self-initiated attention as the KAKENHI (Grant-in-Aid for Scientific Research (A)) project entitled 'Control of audiovisual attention by spontaneous attention,' which was accepted in 2019.

[Cyber-Physical Security Research Group]

For the next-generation information and communication infrastructures such as IoT, M2M, and CPS, we aim to developing advanced information security technologies to ensure security and reliability at the level of vast and diverse information sources (i.e., embedded devices such as sensor terminals) in a vertically integrated manner by various researchers from the viewpoints of software constitutive theory, system security, hardware security, circuit architecture, next-generation microprocessor, and so on. In 2021, we continued discussion about our goal and research direction with several seminars and meetings.

[Brainmorphic Nano-Devices and Circuits Research Group]

Brain-inspired hardware systems have been actively developed recently. However, a big break-through to the true brain-like system has not been reached yet. This research group aims at development and implementation of novel brainmorphic computational hardware that reproduces the bio-physics and dynamics in the brain directly through dynamics and physics of nano-devices and ultra-low-power integrated circuits based on the latest physiological knowledge. Our activities, in this year, to propel collaborative researches on brainmorphic computing from broad perspective including brain science, spintronics, analog/digital integrated circuits, cultured neurocyte, and nonlinear complex dynamics, are illustrated as follows. We supported the JST Sato CREST project, and the Yamamoto project of Grant-in-Aid for Transformative Research Areas (B), which this group thoroughly supported for application. In addition, we organized and participated in a special session of the 2021 Nonlinear Science Workshop. We also collaborated with the thematic program “Designing the Human–Centric IoT Society” of Tohoku Forum for Creativity.

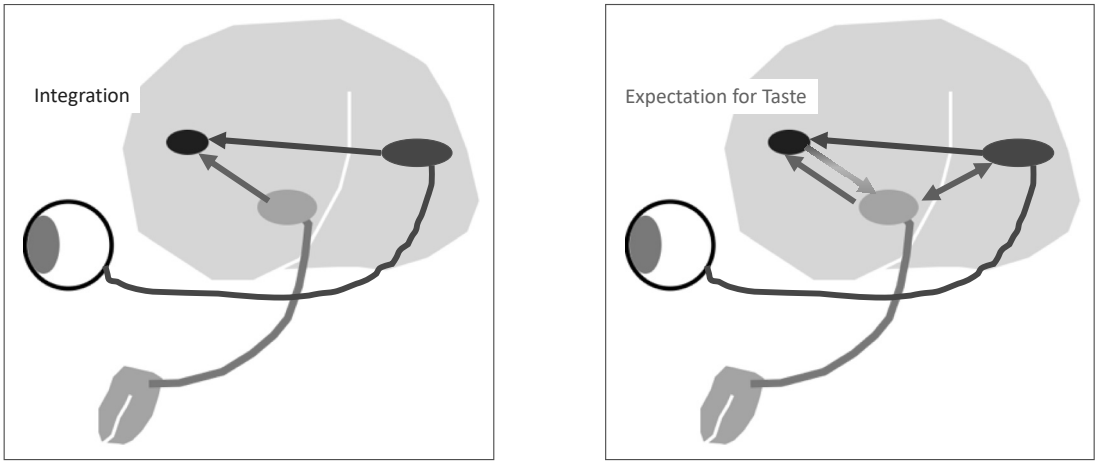
[Group of developing the AI clone system]

The aim of the group is to adopt knowledge of the cognitive science to AI (artificial intelligence) and AR (augmented reality) technology. Specifically, we develop "AI clone", which is the model of recognition and action characteristics of a person. AI clone enables others to re-experience the target person's recognition and action with AR interface. Our goal is to establish the new communication technology that improves mutual understanding among people with differences in a variety of aspects, using AI clone and AR interface. We applied KAKENHI (Grant-in-Aid for Challenging Research) and other research grant to investigate action property of person with visual deficits.

Division for the Establishment of Frontier Sciences

Multimodal Cognitive System Division

Research project on multimodal information integration based on food perception.



Classical Bottom-Up model for perception of food

Top-down model for perception of food in this research

Fig. 1 The model adapted in this research is shown in right panel. The perception of food is based on interactive top-down processing of multimodal sensory inputs, not on simple integration of sensory inputs.

Nobuyuki Sakai, Dr. Professor

[Research Target and Activities]

In this year, we have done some experiments about the followings; the interaction of olfaction and vision, and gustation and vision; the effect of knowledge by dental education on aesthetic evaluation of human faces, and its brain mechanisms investigated by fMRI and fNIRS, etc. We have also started the cognitive studies about the effect of audition on binocular rivalry, the differences of attentional system of vision and of audition, the interactive mechanisms of audition with somatosensation, and the comparison of the effects of vision with audition on affection and arousal.

[Staff]

Professor : Nobuyuki Sakai, Dr.
Assistant Professor : Kosuke Yamamoto

[Profile]

Nobuyuki Sakai graduated from Graduate School of Human Sciences, Osaka University in 1998. Then he worked at Hiroshima Shudo University and National Institute of Advanced and Industrial Science and Technology (AIST) , Kobe Shoin Women's University. He, then, moved to Sendai in October 2011, and he is a professor of Graduate School of Arts and Letters of Tohoku University now.

[Papers]

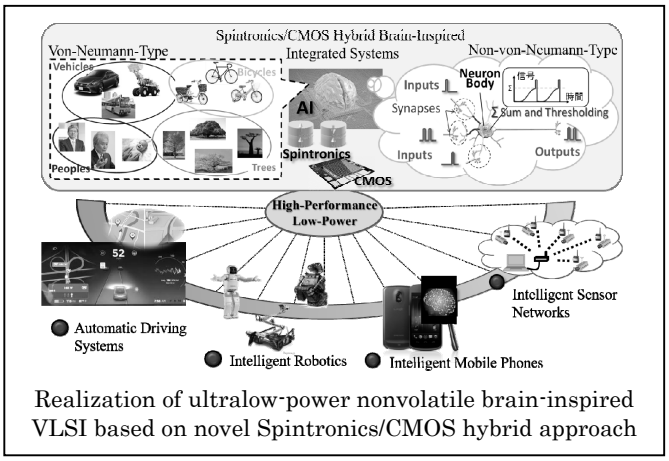
[1] A. Saita, K. Yamamoto, A. Raevskiy, R. Takei, H. Washio, S. Shioiri, and N. Sakai, Crispness, the Key for the Palatability of "Kakinotane": A Sensory Study with Onomatopoeic Words, Foods, 10, 1724, 2021, doi: 10.3390/foods10081724
[2] T. Hasegawa and N. Sakai, Comparing Meal Satisfaction Based on Different Types of Tableware: An Experimental Study of Japanese Cuisine Culture. Foods, 10, 1546, 2021, doi: 10.3390/foods10071546
[3] Raevskiy A., Sakai N. Japanese onomatopoeic words: psychological view of the linguistic phenomenon. MSU Vestnik. Series 13. Oriental Studies, № 3, pp. 84-97, 2021.

Spintronics/CMOS Hybrid Brain-Inspired Integrated Systems

Ultralow-power Spintronics/CMOS hybrid Brain-inspired VLSI for Edge Devices

Spintronics/CMOS Hybrid Brain-Inspired Integrated Systems Tetsuo Endoh, Professor
Spintronics/CMOS Hybrid Brain-Inspired Integrated Systems Yitao Ma, Assistant Professor

[Research Target and Activities]



Realization of ultralow-power nonvolatile brain-inspired VLSI based on novel Spintronics/CMOS hybrid approach

The purpose of our research activity is to break ground for a new AI hardware approach across from the fundamental science of material and information to the devices, circuits, architectures and software technologies to develop the novel high efficient and low power brain-inspired computing hardware system for precise and real-time processing of information value judgment, choice, and refusal. This year, we completed building the verification platform for Spintronics/CMOS hybrid Brain-inspired chips based on software and FPGA demonstration system. Moreover, leveraging our well-equipped CMOS/MTJ hybrid VLSI measurement environment built-up by the last academic year, in the "von Neumann" approach, we successfully completed the evaluation of our nonvolatile adaptive K-means unsupervised learning processor and nonvolatile 16-bit FCNN object detection processor under 55nm-CMOS/ 5Xnm-pMTJ hybrid technology, and also completed the demonstration of a 8bit/16bit hybrid CNN circuit module using FPGA. On the other hand, in the "non-von Neumann" approach, we focused on SNN architecture and finished the evaluation of our novel nonvolatile 32K-Synapse/512-Neuron 8-core/8-layer SNN recognition processor with pulse-driven self-directed power management technique for ultralow-power object recognition accelerators in battery-driven edge devices.

[Staff]

Professor : Tetsuo Endoh, Ph.D.
Assistant Professor: Yitao Ma, Ph.D.

[Profile]

Tetsuo Endoh received the Ph.D. degree in electronic engineering from Tohoku University in 1995. He joined Toshiba Corporation in 1987 and became a Lecturer at the RIEC, Tohoku University, in 1995, an Associate Professor in 1997, and a Professor in April 2008. From 2012, he has been a Professor at the Graduate School of Engineering and director of CIES and CSIS, Tohoku University. He is a JSAP Fellow. He was the recipient of the LSI IP Design Award (2001), the JJAP Paper Award (2009), the 6th Fellow Award of the JSAP (2012), and the SSDM Paper Award (2012), 2020 VLSI Test of Time Award (2021), the 14th Prime Minister's Award for its Contribution to Industry-Academia-Government Collaboration (2017), and National Invention Award (2018).

Yitao Ma received the Ph.D. degree in electronic engineering from The University of Tokyo, in 2011. He works in Tohoku University as an Assistant Professor of the Graduate School of Engineering from 2018, and then an Assistant Professor of the RIEC since 2019. He has been the key member of many projects such as JST-CREST, CSTI-FISRT, JST-ACCEL, CSTI-ImPACT, JST-OPERA, and CSTI-SIP.

[Papers]

[1] Yitao Ma, et al., 5th Symposium of The Core Research Clusters for Materials Science and Spintronics, (Virtual), October 2020.
[2] Tao Li, Yitao Ma, Ko Yoshikawa, Osamu Nomura and Tetsuo Endoh, IEEE Transactions on Industrial Informatics, Vol. 16, Issue 5, pp. 3055 – 3065, August 2021.
[3] Li Zhang, Yitao Ma and Tetsuo Endoh IEEE Transactions on Magnetics, (Early Access), January 2022.
[4] Tetsuo Endoh, Asia-Pacific Workshop on Fundamentals and Applications of Advanced Semiconductor Devices, (Virtual), August 26 2021.
[5] Tetsuo Endoh, The 32nd Magnetic Recording Conference, (Virtual), August 17 2021.

Center for Science and Innovation in Spintronics (CSIS)

＜About the Center＞

Establishment：January 30, 2018

Organization：Director: Yoshio Hirayama (Professor, Graduate School of Science)
Number of academic members: 43 (concurrent members from Grad. School of Science, Grad. School of Engineering, IMR, RIEC, IMRAM, AIMR, FRIS, CSIS, CIES, and CSRN, Tohoku University)

Research Target：Creation of world-leading research center pioneering in so-called “Spin-Centered Science” by strategic consolidation of excellent researchers from foreign leading universities in fundamental and applied fields.

Research Activities：Spin-centered fundamental science, advanced spintronic materials, spintronic devices, and integration technology of spintronic devices.

＜Major Achievements in 2021＞

・Promotion of world-leading research in spintronics

Excellent 9 proposals were adopted to the cooperative research projects in CSIS were adopted to promote international collaborations as well as those beyond the organizations at Tohoku University.

・Fostering excellent early-career researchers

Excellent early-career researchers, 5 persons from foreign countries, were employed as assistant professors or posdoc researchers to promote collaborations beyond the organization at Tohoku University.

・Promoting international academic exchange

Most international workshops to promote academic exchange between CSIS and foreign leading universities were cancelled or postponed in FY2021 due to the influence of COVID-19. The 5th International Symposium for the Core Research Clusters for Materials Science and Spintronics was held via online in October, 2021 and the registrants were about 360 persons. The 1st Online RIEC Workshop on Spintronics was held in November, 2021. The workshop was attracted much attention due to its new style combining on-demand videos of invited talks and a live session.

Center for Innovative Integrated Electronic Systems (CIES)

＜Overview＞

Establishment: The CIES was established in October 2012 to enhance industry-academia collaborations and contribute to further development of the electronics industry. The building of the CIES was constructed in March 2013 as the first Science Park in this country by a private donation located in Aobayama New Campus at Tohoku University.

Organization: Director: Tetsuo Endoh (Professor, Graduate School of Engineering)

Number of staff: 78 (including appointments across Graduate School of Engineering, Graduate School of Information Sciences, RIEC etc.)

Mission: The CEIS researches and develops integrated electronic technologies with various research seeds that Tohoku University has and abundant results of industry-academia collaboration as centripetal force. And the CIES pursues to contribute to the enhancement of global competitiveness in the field of next generation integrated electronics systems by establishing an international industry-academia collaboration base. Further, the CIES aims for practical use of the technologies in this field and is aiming to create new industries.

Research topics: Under the framework of industry-academia joint research, national projects, regional collaboration projects, the CIES has expanded from the world's most advanced spintronics technology, which has been developed at CIES, to AI hardware technology and power electronics technology. While promoting research and development of these three core technologies, we are aiming to develop an innovative integrated electronics system that realizes dramatic power-saving operation that is indispensable for the realization of carbon neutrality and AI / IoT / DX.

＜Major activities in FY2021＞

CIES has managed the “CIES consortium” which consists of industry–academic collaborations, major national projects (JST OPERA, JSPS Core-to-Core, JAXA Space Exploration Innovation Hub, NEDO, METI Tohoku Supporting Industry, MEXT Power Electronics) and regional collaboration projects from material, equipment, devices and system in cooperation with various international and domestic companies aiming for the practical applications of innovative core technologies created by Tohoku University. Our center was selected as the 1st base of the " J-Innovation HUB Initiative", a new project of the METI in 2020. The research and development field has been expanded from spintronics to 3D memory, AI hardware and power electronics, and the industry-academic collaborations have been significantly expanded to twenty. Here, these companies utilized “a special private-sector investment promotion zone system (for information service-related industries)” under a joint application from Miyagi prefecture and local municipalities, and “financial assistance according to the amount of property tax paid (created under an agreement between Tohoku University and Sendai City)”. In June 2021, Tohoku University established the Tohoku University Semiconductor Technology Co-creation to contribute to Japan's semiconductor strategy and, by extension, the world's energy-saving society. In addition to this co-creation, CIES is positioned as a spintronics power-saving logic semiconductor development base in Japan's semiconductor strategy, and we are further strengthening our

efforts to promote industry-academia-government co-creation and social implementation.

CIES has developed a variety of innovative technologies with world-first 300mm wafer process line and facilities operated by the university for prototype manufacturing and characterizing spintronics integrated circuits compatible with world-class companies, and has made progress in developing IoT and AI systems that require ultra-low power consumption. Specifically, we have succeeded in developing a low power consumption MRAM technology that has data retention for more than 10 years and rewrite tolerance that reaches 1 trillion times with the integrated technology of the single digit nanometer generation. The fusion of cutting-edge Xnm semiconductors and spintronics technology paves the way for expanding IoT / AI / environment-tolerance application areas with ultra-low power consumption and high-performance edge devices. In addition, it has been adopted by the NEDO Post 5G Information and Communication Systems Infrastructure Reinforcement R&D Project and NEDO AI Computing R&D Project related to semiconductor strategy, and we are enhancing the development of this technology. In the field of power electronics, we are working to improve the functionality, size and weight of motor drive inverters and DC-DC converters by taking advantage of the low loss and high frequency operation of GaN on Si power devices. It has been adopted by the MEXT innovative power electronics creation basic technology R&D project, and we are accelerating the R&D of integrated power electronics. Utilizing the three core technologies of spintronics technology, AI hardware technology and power electronics technology, which are the world's most advanced technologies that have been researched and developed at CIES, we aim to develop IoT/AI system, which is indispensable for realizing carbon neutrality and requires ultra-low power consumption.

Aiming to contribute to the development of the innovative integrated electronics business and further advancement of industry-academia collaboration, Power Spin Inc., a startup company from Tohoku University, is now in its fourth year, and it has been put into practical use based on the technology and know-how of this center. In addition to Miyagi Prefecture, the Miyagi Advanced Electronics and Machinery Industry Association, the Miyagi Automotive Industry Promotion Council, Iwate Prefecture, Iwate Semiconductor and Electronics Industries Promotion Conference, local and local companies in Yamagata Prefecture was added, and regional cooperation was expanded with cooperation of the METI Tohoku.

In order to establish world leading R&D base for integrated electronic systems and AI hardware, we will continue to create innovative core technologies and contribute to the industry and the enhancement of global competitiveness by the practical applications, and “new creation and innovation” through global and regional partnership.

Research Organization of Electrical Communication（ROEC）

Towards Construction of Disaster-Resistant Information Communication Network

[Purpose of our establishment]
Many serious problems have become clear as a result of the Great East Japan Earthquake, which exposed the weaknesses of the most advanced information communications network in the world by severing the mobile phone and optical fiber lines thus cutting off essential telecommunications services. To solve these problems, Tohoku University's Disaster Reconstruction and Regeneration Research Project includes an ICT Reconstruction Project for restoring information communication. The mission given to the researchers in the Electrical Engineering and Information Sciences group after the disaster was to achieve a disaster-resistant information communication network through the ICT Reconstruction Project, taking the needs of the disaster areas into consideration.
To realize this network, we needed to employ the combined strength of our problem-solving abilities by linking researchers in electrical engineering and the information sciences across multiple faculties, including the School of Engineering, the Graduate School of Information Sciences, the Graduate School of Biomedical Engineering, the Cyberscience Center, and the Research Institute of Electrical Communication. These faculties and schools came together to form a new organization that could create close and flexible links between researchers and organizations, and on October 1, 2011 we established the Research Organization of Electrical Communication (ROEC) (Fig.1). The ROEC intends to take an all-Japan approach based on collaboration between industry, academia and government, and assemble expertise from the university with the participation of related local governments, private companies, public research organizations, and other universities with the goal of developing the most advanced disaster-resistant information communication network in the world (Fig.2).

[Main Activities]
Since 2012, we have been promoting 12 disaster-resilient ICT projects supported by the Ministry of Internal Affairs and Communications. In 2020, six ongoing projects were promoted. We have also been engaged in project supported by OPERA, JST. As a result of resilience ICT research and development, we gave a lecture on Beyond 5G research results at Next Generation Safe and Secure ICT Forum. The research results produced by the promoted projects were presented in ROEC Homepage.

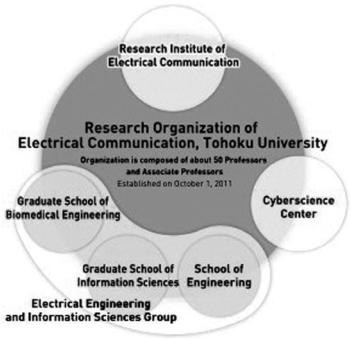


Fig.1 Research Organization of Electrical Communication.

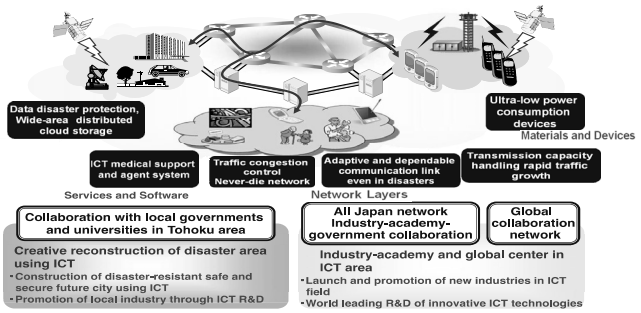


Fig.2 Overview of ICT Reconstruction Project.

[Staff]
Prof. Hirohito Yamada (Executive Director)
Prof. Taiichi Otsuji (Vice Executive Director)
Specially Appointed Prof. Hiroyuki Ogawa (Vice Executive Director)
Specially Appointed Prof. Katsumi Iwatsuki (Research Administrator)
Mr. Yoichi Mikami (Office Manager)
Ms. Ayako Murakami (Manager)

[Papers]
[1] Ryo Takahasi, Hidenori Matsuo, and Fumiyuki Adachi,"Joint multi-layered user clustering and scheduling for ultra-dense RAN using distributed MIMO,"IEICE Trans. Communications, Vol.E104-B, No.9, pp.1097-1109, Sept. 2021.
[2] Kozo Sato, Takashi Kan, Masato Yoshida, Keisuke Kasai, Toshihiko Hirooka, and Masataka Nakazawa, "Chromatic dispersion dependence of GAWBS phase noise compensation with pilot tone," Opt. Express, vol. 29, no. 7, pp. 10676-10687 (2021).
[3] Liu Ke, Hirohito Yamada, Katsumi Iwatsuki, and Taiichi Otsuji, " A study for stable operation of battery loaded DC bus based on autonomous cooperative control", 2021 The 6th International Conference on Power and Renewable Energy, DOI:10.1109/ICPRE52634.2021.9635250, September 25 (2021).

Center for Spintronics Research Network（CSRN）

＜About the Center＞

Establishment：April 1, 2016

Organization：Director: Koki Takanashi (Professor, IMR)
Number of academic members: 62 (including 1 full-time member and the other concurrent members from Grad. School of Science, Grad. School of Engineering, IMR, RIEC, IMRAM, AIMR, CSIS, CIES, and FRIS, Tohoku University)

Research Target：The center will be the hub of a network to promote collaborations with other research institutions within Japan and overseas, aiming to (1) improve competitiveness of world-leading spintronics research in Japan, (2) create new branches and enhance existing areas of industry, and (3) foster the next- generation human resources.

Research Activities：[Spintronics Device Creation Division]
We develop advanced systems and devices for energy creation and energy saving by using spintronics technology to provide eco-friendly infrastructure and to innovate conventional information and communication technology.
[Spintronics Device Characterization Division]
We develop advanced measurement techniques to characterize the behavior of spins in integrated spintronics devices. We also clarify the physical mechanism of the behavior of spins in spintronics devices theoretically to propose innovative spintronics devices.

＜Major Achievements in 2021＞

・Cooperative Research Project

We adopt 65 cooperative research projects to promote collaborations with other spintronics researchers. The collaborators belong 41 institutions in Japan and 36 overseas institutions (in 16 countries). For detail, see the following URL: http://www.csrn.tohoku.ac.jp/

・Share of Experimental Facilities and Equipment

We offer 23 facilities and equipment for sharing with researchers in spintronics. The list of shared facilities/equipment is open to the public at the above URL.

・Academic Meetings

For promoting exchange and fostering human resources of spintronics researchers, CSRN jointly hosted 5 international conferences, 2 domestic workshops, and 2 seminars/schools.

CSRN was reorganized and integrated as a division of the Center for Science and Innovation in Spintronics (CSIS), Tohoku University on April 1, 2022.

Advanced Institute for Yotta Informatics

＜About the Center＞

Establishment：April 1, 2018

Based on research activities as a Program for Key Interdisciplinary Research of Tohoku University from 2015 to 2017, Yotta Informatics Research Center is granted by MEXT in 2018.

Organization：Director: Satoshi Shioiri (Director, Professor, RIEC)

Number of members: 34 (RIEC, Graduate School of Engineering, AIMR, Graduate School of Arts & Letters, Graduate School of Information Sciences, Graduate School of Economics and Management, Graduate School of Biomedical Engineering, Graduate School of Education, Graduate School of Life Sciences)

Research Target：Novel science and technology to manage both quantity and quality of yotta-scale information, in order to establish the future ICT technology and new humanics by collaborative work of engineering and human and social science.

Research Activities：The amount of information is rapidly increasing, which is projected to reach to the amount of one yotta (10^{24}) bytes. Ordinary extension technology of the conventional ICT cannot cope with such gigantic amount of information, therefore essential paradigm change for the information processing is indispensable. In this institute, we aim at the new information science, which can manage the quality of information as well as the information amount. For the sake, experts of information engineering, human and social science from departments are discussing about interdisciplinary collaborating works to understand the quality and value of information, as well as the quantity. The value information is the key properties for the future informatics to receive the full benefit of the information in the upcoming “beyond the big data” era.

＜Major Achievements in 2021＞

1. We have started 9 interdisciplinary projects that lead the new information science, which can manage the quality of information as well as the information amount and select important information appropriately. We published 107 papers and 208 presentations (including 46 invited talks), and executed 79 projects supported by external grants.
2. We organized an international symposium “Symposium of Yotta Informatics – Research Platform for Yotta-Scale Data Science 2019” and co-organized a RIEC international symposium “Tohoku U - NTU Symposium: When AI Meets Human Science," and invited many researchers from inside and outside of Japan. We also conducted an IEEE ISCAS special session and three special sessions of IEICE meetings.
3. We edited a special section of Interdisciplinary Information Sciences (IIS), “New informatics paradigm to manage quality and value of information.”

Leading Graduate Program “Interdepartmental Doctoral Degree Program for Multi-Dimensional Materials Science Leaders”

＜Overview＞

Establishment：October, 2013
This program was adopted as a Program for Leading Graduate Schools of JSPS.
(The financial support from JSPS was finished in FY2019.)

Organization：Program manager: Masahiro Yamaguchi
(Vice President for Educational Reforms and International Strategy)
Program coordinator: Tetsuya Nagasaka (Professor, Grad. School of Engineering)
Program members: 59 academic staffs in Tohoku University

Mission：Fostering human resources through creating leaders who have a firm grasp of the fundamentals of material science and extensive research experience. The term “multi-dimensional” (MD) refers to the extensive, panoramic perception of materials through dimensions such as functionalities, characteristics, processes, environmental compatibility, economics, safety, and assessment techniques.

＜Major Achievements in 2021＞

The Qualifying Examination 2 (QE2) was held via online on May 26, 2021 and from November 30 to December 1, 2021. As a result, 10 students in total of the MD program passed QE2. An alumni of the MD program, who is a researcher in National Institute for Materials Science (NIMS), received the L’Oréal-UNESCO “For Women in Science” Japan Fellowships on November 4, 2021.

Graduate Program in Spintronics (GP-Spin)

＜Overview＞

Establishment：April 1, 2015

Organization：Head of the Division for International Joint Graduate School Programs: Masahiro Yamaguchi (Vice President for Education Reform and Global Engagement)
Graduate Program in Spintronics (GP-Spin) Program Director: Yoshiro Hirayama (Professor, Graduate School of Science)
Program members: 21 academic staffs in Tohoku University
Foreign organization: Johannes Gutenberg Univ. Mainz (Germany), Univ. Regensburg (Germany), Tech. Univ. Kaiserslautern (Germany), Tech. Univ. München (Germany), Univ. Lorraine (France), Univ. Chicago (USA), Tech. Univ. Delft (The Netherland), Univ. Groningen (The Netherland), University of York (UK), University of Leeds (UK), Polish Academy of Sciences (Poland), Tsinghua University (Chaina)

Mission：Education of world-class leaders in spintronics from fundamental to applications

Activities：(1) Education by world-leading professors from all departments and institute in Tohoku University with participation from all over the world
(2) Joint education with foreign organization including joint supervised degree/joint degree, mutual visit and long-term internship, international school/workshop, qualifying examination to guarantee the educational quality

＜Major Achievements in 2021＞

Although most seminars and lectures were cancelled or postponed due to COVID-19 in FY2021, the Students' Workshop on "Spintronics with Quantum Beams" was held via online on November 5, 2021. The workshop contains 5 invited talks and poster presentations by the students of GP-Spin. The workshop to improve the students' skills of presentation in English was held at Advanced Institute of Materials Research, Tohoku University on December 7, 2021.

Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan
WISE Program (Doctoral Program for World-leading Innovative & Smart Education)
Advanced Graduate Program for AI Electronics

＜About the Center＞

Establishment：Adopted October, 2018.
It has been adopted by the WISE Program (Doctoral Program for World-leading Innovative & Smart Education) of MEXT. This program is a new education program that starts from FY 2018.

Organization：Chief executive: Hideo Ohno (President of Tohoku University)
Program leader: Masahiro Yamaguchi (Vise-President of Tohoku University (Education Reform / International Strategy))
Program coordinator: Toshiro Kaneko (School of engineering, Professor)
Program manager: Approximately 70 people (including managers and a coordinator)

Target of Program：In this Graduate School Program, we will foster world-class talented doctors who can make an innovation continuously through the learning of “an practical ability”, “solving of social problems”, “creation of novel value”, and “an ability that can see real space and cyberspace in Society 5.0 with wide perspectives”.

＜Major Achievements in 2021＞

The program has launched a PBL (Project Based Learning) course, which is an original course of the WISE program. This PBL course was jointly developed and implemented by 12 sponsoring companies and university faculty members and forms the core of industry-academia collaborative education. After completing the course, a symposium was held and students made presentations on the results of their studies in the course. As an internship program at the COVID-19 disaster, students of the program participated in internships at overseas and domestic companies by combining on-site and online training. In addition, five AIE lectures and a two-day international symposium were held, in which prominent professors from Japan and abroad gave lectures on a wide range of topics, from basic technologies to applications and issues in the social practice of artificial intelligence electronics. All students in the program presented their research in English at the international symposium. We recruited and selected students for the fourth term, and 26 new students (11 new M1 students, 11 new M2 students, and 4 new D1 students) were selected.

4. Nation-wide Cooperative Research Projects

The Institute has a long history of fundamental contributions in many fields of engineering and science that include the fields of semiconductor materials and devices, magnetic recording, optical communication, electromagnetic technology, wireless communication, applications of ultrasonic communication and acoustic communication, non-linear physics and engineering, and computer software. On the basis of this rich historical background the Institute was designated as a National Center for Cooperative Research in 1994. Accompanying Tohoku University's transformation to "a national university juridical entity" in April, 2004, this institution plays a leading role on the world stage, as its researchers, both domestic and foreign, continue the task of "investigating the theory and application of universal science and technology to realize communication, to the enrichment of humanity."

With this background, the Institute organizes Nation-wide Cooperative Research Projects by coordinating its activities with research workers. The main themes for Cooperative Research are selected annually by the Committee for Cooperative Research Projects. Then invitations for project proposals and participation are extended to university faculties and government laboratories as well as industrial research groups. Each project approved by the Faculty Council of the Institute is carried out by a team of researchers that include members of the Institute as well as outside participants.

The Advisory Council which includes members from other institutions has an advisory function to the Director in defining the general direction of the research at the Institute and its Nation-wide Cooperative Research Projects.

The Project Selection Committee that includes members from outside of Tohoku University has a Judging function for project proposals. The purpose of the Project Steering Committee is the proper operation of approved projects.

Nation-wide Cooperative Research Projects List 2021

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
H31/A01	Japan-USA International Collaborative Research on Terahertz Devices based on Graphene-Phosphorene van der Waals Heterostructures	**MITIN, Vladimir** Department of Electrical Engineering, University at Buffalo, The State University of New York	**OTSUJI Taiichi**
H31/A04	Formation of Self-Aligned Si-Ge based Quantum Dots and Characterization of Their Electrical Properties	**MIYAZAKI Seiichi** Graduate School of Engineering, Nagoya University	**SATO Shigeo**
H31/A05	Quantifying the role of crystal and magnetic structure to spin-orbit torque induced switching of metallic antiferromagnetic heterostructures	**TRETIAKOV/Oleg** School of Physics, University of New South Wales	**FUKAMI Shunsuke**
H31/A06	Development of efficient magnetization-switching devices using transition-metal compounds	**ISOGAMI Shinji** Research Center for Magnetic and Spintronic Materials, National Institute for Materials Science	**SHIRAI Masafumi**
H31/A07	Development of high Q microwave resonators for quantum detection	**INOMATA Kunihiro** Nanoelectronics research institute, Advanced Industrial Science and Technology	**SATO Shigeo**
H31/A09	Development of non-volatile phase transition oxide elements targeting application for optoelectronics	**SAKAI Joe** Materials system division,Toshima Manufacturing Co.,Ltd	**KATANO Satoshi**
H31/A10	Study of magnetization dynamics induced by the spin orbit torque and the phase locking via spin waves for dc drive microwave oscillators	**KODA Tetsunori** General Education Division, National Institute of Technology, Oshima College	**ISHIYAMA Kazushi**
H31/A11	High-Speed Driver for Optical Modulators using InGaAs HEMTs with Slant Field Plates	**UMEDA Yohtaro** Faculty of Science and Technology, Tokyo University of Science	**SATOU Akira**
H31/A12	Study of the open environment for sharing vision models	**SAKAI Ko** Faculty of Engineering Information and Systems, Tsukbua University	**SHIOIRI Satoshi**
H31/A13	Communication system for controlling human cognition and behavior from kansei information speech	**TANAKA Akihiro** Department of Psychology, Tokyo Woman's Christian University	**SAKAMOTO Shuichi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
H31/A18	Development of compact quantum light source using a gain-switching laser diode	**MATSUDA Nobuyuki** Graduate School of Engineering, Tohoku University	**EDAMATSU Keiichi**
H31/A19	Exploration of a new electrical detection method of magnetization dynamics in CoFeB-MgO magnetic tunnel junction structure with perpendicular anisotropy	**Eli Christopher Inocencio Enobio** Department of Physics, Mindanao State University-Iligan Institute of Technology	**FUKAMI Shunsuke**
H31/A21	A Study on Phase Alignment Accuracy of Software Defined Radio for Rapid Prototyping	**YAMADA Yoji** Department of Electronics and Information Engineering, National Institute of Technology, Ishikawa College	**SUEMATSU Noriharu**
H31/A23	Development of re-experiencing system for learning supports	**SHIOIRI Satoshi** Research Institute of Electrical Communication, Tohoku University	**SHIOIRI Satoshi**
H31/A24	Performance Analysis for Heterogeneous Environment of Internet Congestion Control	**UTSUMI Satoshi** Faculty of Symbiotic Systems Science, Fukushima University	**HASEGAWA Go**
H31/A26	Study of 2D nanomaterial devices for terahertz applications	**AMINE El Moutaouakil** Department of Electrical Engineering, United Arab Emirates University	**OTSUJI Taiichi**
H31/A28	Wireless Propagation Channel for Body Area Network	**AKIMOTO Kohei** Department of Intelligent Mechatronics, Akita Prefectural University	**SUEMATSU Noriharu**
R02/A01	Development of graphene based devices for terahertz applications	**MEZIANI Yahya Moubarak** Dept. Fisica Aplicada, Salamanca University	**OTSUJI Taiichi**
R02/A02	Analyses and mathematical modeling of the function of artificial neuronal circuit	**TANII Takashi** Faculty of science and engineering, Waseda university	**YAMAMOTO Hideaki**
R02/A03	Development of optoelectronic devices based on two-dimensional materials	**UCHINO Takashi** Department of Electrical and Electronic Engineering, Tohoku Institute of Technology	**OTSUJI Taiichi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R02/A04	Spin transport and magnetism in 2D van der Waals ferro and antiferromagnets	**Singh Ravi Prakash** Department of Physics, Indian Institute of Science Education and Research Bhopal	**FUKAMI Shunsuke**
R02/A05	New Group-IV Semiconductor Materials and Highly-Integrated Device Process	**SAKURABA Masao** Research Institute of Electrical Communication, Tohoku University	**SAKURABA Masao**
R02/A06	Development of piezoelectric constant distribution measurement system in micrometer area	**ODAGAWA Hiroyuki** Innovative Research Center, National Institute of Technology, Kumamoto College	**CHO Yasuo**
R02/A07	Beta-Ga2O3 thin film and device fabrication by the sputtering process	**IMAIZUMI Fuminobu** Department of Mechanical Engineering, National Institute of Technology, Oyama College	**SUEMATSU Noriharu**
R02/A08	Study on Electromagnetic Crosstalk Suppression in Mobile Devices Using Negative Magnetic Permeability Materials	**MUROGA Sho** Graduate School of Engineering Science, Akita University	**ISHIYAMA Kazushi**
R02/A09	Control of quantum transport in metal nanojunctions and its application to functional devices	**SHIBATA Kenji** Department of Electrical and Electronic Engineering, Tohoku Institute of Technology	**OTSUKA Tomohiro**
R02/A10	Investigation of physical structure model of high-k/Ge interface affected by fabrication processes	**OTANI Yohei** Department of Mechanical and Electrical Engineering, Suwa University of Science	**SATO Shigeo**
R02/A11	Single-crystal graphene functional device	**NAGASE Masao** Institute of Post-LED Photonics, Tokushima University	**OTSUJI Taiichi**
R02/A12	Japan-Russia International collaborative research on a large-area photoconductive terahertz detector for high-speed imaging	**DMITRY Ponomarev** Laboratory of high-power microwave and mm-wave applications,Institute of ultra high frequency semiconductor electronics of Russian academy of sciences	**OTSUJI Taiichi**
R02/A13	Ultra-low-latency video coding for 8K high-resolution image sensing	**MATSUMURA Tetsuya** College of Engineering, Nihon University	**OTSUJI Taiichi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R02/A14	Development of Wireless Massive Connect IoT	**OGUMA Hiroshi** Department of Electronics and Computer Engineering, National Institute of Technology, Toyama College	**SUEMATSU Noriharu**
R02/A15	A study on over 100GHz-band/optical fiber feed direct digital RF transceiver	**SUEMATSU Noriharu** Research Institute of Electrical Communication, Tohoku University	**SUEMATSU Noriharu**
R02/A16	Study on development of millimeter wave antenna using 3D printer	**ITOH Keiichi** Department of Electrical and Information Engineering, National Institute of Technology, Akita College	**SUEMATSU Noriharu**
R02/A19	Development of device modules that embed sensors onto objects and its application	**MANABE Hiroyuki** Department of Computer Science and Engineering, Shibaura Institute of Technology	**TAKASHIMA Kazuki**
R02/A20	Understanding and reconstruction of minimal brain	**KAMIYA Haruyuki** Graduate School of Medicine, Hokkaido University	**HIRANO Ayumi**
R02/A21	The shape variation of human pinna and its effect on the acoustical transfer function.	**ITO Masashi** Faculty of Engineering, Tohoku Institute of Technology	**SAKAMOTO Shuichi**
R02/A22	Research on the development of a new generation IoT platform	**ZABIR Salahuddin Muhammad Salim** Department of Creative Engineering, National Institute of Technology, Tsuruka College	**KITAGATA Gen**
R02/A23	Exploring and Understanding Touch Interaction using a Slidable-Sheet on Smart Devices	**SAYAN Sarcar** Faculty of Library, Information and Media Science, University of Tsukuba	**FUJITA Kazuyuki**
R02/A24	Investigating cultural issues for the design of touch-based interactive D-FLIP photo management system	**CHINTAKOVID/Thippaya** Department of Library Science, Faculty of Arts, Chulalongkorn University	**KITAMURA Yoshifumi**
R02/A25	Multimodal Data Flow Processing Platform for Enhancing Human Abilities	**MINENO Hiroshi** Faculty of Informatics, Shizuoka University	**KITAGATA Gen**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R02/A27	Multilingual research of cultural and individual differences in color lexicon	**TOKUNAGA Rumi** College of Liberal Arts and Sciences, Chiba University	**HATORI Yasuhiro**
R02/A29	Cultural background and auditory selective attention	**KIM Sungyoung** ECT Engineering Technology, Rochester Institute of Technology	**SAKAMOTO Shuichi**
R02/A30	Research for feedforward regulation of the visual and sensory systems via cardiovascular regulation	**ISHII Kei** Automotive Human Factors Research Center, National Institute of Advanced Industrial Science and Technology	**HATORI Yasuhiro**
R02/A31	Constructive research on nonlinear complex systems and development of their theories	**HORIO Yoshihiko** Research Institute of Electrical Communication, Tohoku University	**HORIO Yoshihiko**
R02/A32	Determinants of multisensory auditory space perception	**HONDA Akio** Faculty of Informatics, Shizuoka Institute of Science and Technology	**SAKAMOTO Shuichi**
R02/A33	Research for In-Storage/Memory Computing Platform for Brain Near-Science	**TANAKA Yoichiro** Research Institute of Electrical Communication, Tohoku University	**TANAKA Yoichiro**
R03/A01	A study of the radiation effect on spintronics devices for space application	**WATANABE Kyota** Research and Development Directorate, Japan Aerospace Exploration Agency	**FUKAMI Shunsuke**
R03/A02	Development of Multi-Functional Integrated Circuit on Si/Ge Hybrid Platform	**YAMAMOTO Keisuke** Faculty of Engineering Sciences, Kyushu University	**SAKURABA Masao**
R03/A03	Control of spin dynamics in non-magnetic materials	**ISHIHARA Jun** Department of Applied Physics, Faculty of Science, Tokyo University of Science	**KANAI Shun**
R03/A04	Creation of Bio-Medical Devices Utilizing Non-Equilibrium Plasma-Producing Reactive Species	**KANEKO Toshiro** Graduate School of Engineering, Tohoku University	**HIRANO Ayumi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R03/A05	Electric-field control of magnetic topological materials for non-volatile magnetic memories	**CHIBA Takahiro** General Education, National Institute of Technology, Fukushima College	**TSUJIKAWA Masahito**
R03/A06	R&D on radiation response of quantum devices	**KISHIMOTO Yasuhiro** Research Center for Neutrino Science, Tohoku University	**OTSUKA Tomohiro**
R03/A07	Development of Quantum Device based on Atomically Thin Layered Materials	**KATO Toshiaki** Graduate School of Engineering, Tohoku University	**OTSUKA Tomohiro**
R03/A08	Elucidation of nano-photoelectronic properties of nanocarbons for optical functionalizations	**KATANO Satoshi** Research Institute of Electrical Communication, Tohoku University	**KATANO Satoshi**
R03/A09	Research of on-chip THz array antenna for ultra-wideband communication	**KANAYA Haruichi** Graduate School of Information Science and Electrical Engineering, Kyushu University	**SUEMATSU Noriharu**
R03/A10	High frequency chaos circuits using RTDs and their applications	**MAEZAWA Koichi** Graduate School of Science and Engineering, University of Toyama	**OTSUJI Taiichi**
R03/A11	Millimeter-wave large-scale array antenna for wireless terminal application	**YOSHIDA Satoshi** Research Field in Engineering, Science and Engineering Area, Research and Education Assembly, Kagoshima University	**SUEMATSU Noriharu**
R03/A12	Study on energy harvesting and meta-surface applied for 5G /IoT	**MARUYAMA Tamami** Department of Production Systems Engineering, National Institute of Technology, Hakodate College	**SUEMATSU Noriharu**
R03/A13	Study of delay-sensitive and seamless access networks using widely frequency selectable optoelectronics integrated devices	**YOSHIMOTO Naoto** Faculty of Science and Technology, Chitose Institute of Science and Technology	**OTSUJI Taiichi**
R03/A14	Mixed Reality for IoT and Robotics: Opportunities and Challenges for Immersive Human-Robot Interaction	**SUZUKI Ryo** Department of Computer Science, University of Calgary	**KITAMURA Yoshifumi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R03/A15	Reconfigurable Head-Mounted Displays Enabling Real-world Interactions	**KIYOKAWA Kiyoshi** Graduate School of Science and Technology, Nara institute of science and technology	**KITAMURA Yoshifumi**
R03/A16	An investigation on spatio-temporal characteristics of auditory selective attention	**TERAOKA Ryo** Graduate School of Humanities and Social Sciences, Kumamoto University	**SAKAMOTO Shuichi**
R03/A17	Study on sound space perception under limited binaural cue condition	**MORIKAWA Daisuke** Faculty of Engineering, Toyama Prefectural University	**SAKAMOTO Shuichi**
R03/A18	Basic research on mental state recognition based on physiological and psychological data of online learners	**OMATA Masaki** Graduate Faculty of Interdisciplinary Research, Yamanashi University	**KITAGATA Gen**
R03/A19	Assessing the effectiveness of sitting-standing interventions for cognitive performance improvement	**Tag Benjamin** Melbourne School of Engineering, School of Computing and Information Systems,he University of Melbourne	**KITAMURA Yoshifumi**
R03/A20	Neuromorphic Systems using Thin-Film Memcapacitors	**KIMURA Mutsumi** Faculty of Science and Technology, Ryukoku University	**HORIO Yoshihiko**
R03/A21	A Classification System for Encrypted Communications Caused by Malware	**SATOH Akihiro** Information Science Center, Kyushu Institute of Technology	**KITAGATA Gen**
R03/A22	IoT security technologies	**OGUMA Hiroshi** Kyushu Institute of Technology, National Institute of Technology, Toyama College	**HOMMA Naofumi**
R03/A23	Development of Advanced Harmonized Agent Platform	**UCHIYA Takahiro** Information Technology Center, Nagoya Institute of Technology	**SAKAMOTO Shuichi**
R03/A24	Development of a sensitive CO gas sensor with TiO2 nanotube	**KIMURA Yasuo** School of Engineering, Tokyo University of Technology	**HIRANO Ayumi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R03/A25	Creation of device informatics and its application to Beyond 5G devices	**FUKIDOME Hirokazu** Research Institute of Electrical Communication, Tohoku University	**FUKIDOME Hirokazu**
R03/A26	Quantum research based on integration of experimental, theoretical and data science	**SHIGA Motoki** Faculty of Engineering, Gifu University	**OTSUKA Tomohiro**
R03/A27	Investigation of contactless power transmission in a long distance	**INAMORI Mamiko** Department of Electrical and Electronic Engineering, Tokai University	**SUEMATSU Noriharu**
R03/A28	Embodiment of space perception: anisotropy and individual difference	**TERAMOTO Wataru** Graduate School of Social and Cultural Sciences, Kumamoto University	**SAKAMOTO Shuichi**
R03/A29	Application of high-performance soft magnetic alloys to advanced devices	**SUZUKI Shigeru** Micro System Integration Center, Tohoku University	**ISHIYAMA Kazushi**
R03/A30	Effects of body vibration generated from audio-visual signal on perceived reality in multimodal contents	**CUI Zhenglie** Media Informatics, Aichi University of Technology	**SAKAMOTO Shuichi**
R03/A31	Research on the formation of a gravity observation network using optical communication technologies and the monitoring of volcanic activities	**ARAYA Akito** Earthquake Research Institute, The University of Tokyo	**KASAI Keisuke**
R03/A32	Hardware Technology for Brain Computing and its Application to Edge Computing	**SATO Shigeo** Research Institute of Electrical Communication, Tohoku University	**SATO Shigeo**
R03/A33	Animating characters for virtual reality	**KOMURA Taku** Department of Computer Science, University of Hong Kong	**KITAMURA Yoshifumi**
H31/B01	Information-related Functional Expression in Hybrid Plasmas of Physical and Chemical Systems	**KOGA Kazunori** Faculty of Information Science and Electrical Engineering, Kyushu University	**SATO Shigeo**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
H31/B02	Precise understanding and function development of non-equilibrium dynamics in solid state devices	**KOBAYASHI Kensuke** Graduate School of Science, The University of Tokyo	**FUKAMI Shunsuke**
H31/B03	Studies on Elemental Technologies for Development of The Next Generation Wireless Communication Systems	**KONNO Keisuke** Graduate School of Engineering, Tohoku University	**SUEMATSU Noriharu**
H31/B04	Development of next-generation academic community that applies human-computer interaction researches	**SAKAMOTO Daisuke** Graduate School of Information Science and Technology, Hokkaido University	**KITAMURA Yoshifumi**
H31/B06	Visual KANSEI mechanisms for SHITSUKAN and color perception	**OKAJIMA Katsunori** Faculty of Environment and Information Sciences, Yokohama National University	**HATORI Yasuhiro**
H31/B08	Study group on UAV application/technology and its social implementation for regional revitalization	**SUEDA Koh** Smart System Institute, National University of Singapore	**KITAMURA Yoshifumi**
H31/B09	New development of practical research on microwave and laserbased synthetic aperture radar	**KOGI Yuichiro** Department of Engineering, Fukuoka Institute of Technology	**YASAKA Hiroshi**
H31/B11	A study on static analysis for a dynamic language and its realization	**MATSUMOTO Yukihiro** Ruby Association	**UENO Katsuhiro**
H31/B12	User Interface for Viewing and Editing Complex Graph Contents	**FUJITA Kazuyuki** Research Institute of Electrical Communication, Tohoku University	**FUJITA Kazuyuki**
H31/B13	spin-orbit dynamics and its control in solid states	**KOHDA Makoto** Graduate School of Engineering, Tohoku university	**KANAI Shun**
H31/B15	Studies on Generative Technology for Enriched Multimedia	**SONODA Kotaro** Graduate School of Engineering, Nagasaki University	**SAKAMOTO Shuichi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
H31/B16	Efficient Reliable Software Construction by Type-directed Compilation	**MORIHATA Akimasa** Graduate School of Arts and Sciences, The University of Tokyo	**UENO Katsuhiro**
H31/B17	PSDL2+: Advanced Physical Security of Deep Learning 2	**BHASIN Shivam** Temasek laboratories, Nanyang Technological University, Singapore	**HOMMA Naofumi**
H31/B18	Study of Dynamic Service Orchestration for Mobile Edge Computing	**SHAO Xun** Division of Information and Communication Engineering, Kitami Institute of Technology	**HASEGAWA Go**
R02/B02	Coherent Communication and Measurement Systems Incorporating Lightwave and Microwave	**INOUE Takashi** Electronics and Photonics Research Institute, National Institute of Advanced Industrial Science and Technology	**HIROOKA Toshihiko**
R02/B03	Layerless Design of Future Wireless Communications and Its Applications	**ISHIBASHI Koji** Advanced Wireless and Communication Research Center, The University of Electro-Communications	**SUEMATSU Noriharu**
R02/B04	Research on Wireless Technologies for the Beyond-5G System	**KUKI Takao** School of Science and Engineering, Kokushikan University	**SUEMATSU Noriharu**
R02/B06	Spatial User Interface by Understanding Human's Physical and Spatial Behaviors	**YAMAMOTO Goshiro** Kyoto University Hospital, Kyoto University	**TAKASHIMA Kazuki**
R02/B07	Human / Social Sensing Infrastructure by Heterogeneous Data Fusion	**OKABE Yasuo** Academic Center for Computing and Media Studies, Kyoto University	**OTSUJI Taiichi**
R02/B11	Development for automation of crows' behavior control method using vocal communication	**TSUKAHARA Naoki** CrowLab Inc	**KITAMURA Yoshifumi**
R02/B12	International Research Collaboration of Brainware LSI and Its Emerging Technologies	**HANYU Takahiro** Research Institute of Electrical Communication, Tohoku University	**HANYU Takahiro**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R02/B14	Self-motion perception and multisensory integration in 3D space	**SAKURAI Kenzo** Faculty of Liberal Arts, Tohoku Gakuin University	**SAKAMOTO Shuichi**
R02/B15	Measurement and control of the functions of lipid bilayer membrane and membrane proteins based on microfabrication technology and nanomaterials	**TERO Ryugo** Department of Environmental and Life Sciences, Toyohashi University of Technology	**HIRANO Ayumi**
R03/B01	Development of new physical phenomena at interfaces brought on by electron spins, orbitals and multipoles	**MIURA Yoshio** Research center for magnetic and spintronic materials, National Institute for Materials Science	**SHIRAI Masafumi**
R03/B02	Research and Development on Precise Optical Mode Control	**HAMAMOTO Kiichi** Faculty of Engineering Sciences, Kyushu University	**YOSHIDA Masato**
R03/B03	A method for modeling of intellectual productivity and computational intervention for productivity enhancement	**ITOH Yuichi** Graduate school of Information Science and Technology, Osaka University	**TAKASHIMA Kazuki**
R03/B04	Functionalization of oxide surfaces and its application to biosensor devices	**HIROSE Fumihiko** Graduate School of Science and Engineering, Yamagata University	**HIRANO Ayumi**
R03/B05	High-dimensional and spatiotemporal neurodynamics and its system applications	**HIROSE Akira** Graduate School of Engineering, The University of Tokyo	**SATO Shigeo**
R03/B06	Theory and implementation for control-less wireless power supply systems	**SEKIYA Hiroo** Graduate School of Engineering, Chiba University	**HORIO Yoshihiko**
R03/B07	A Study on Adaptive Workspaces in the After-Corona Era	**FUJITA Kazuyuki** Research Institute of Electrical Communication, Tohoku University	**FUJITA Kazuyuki**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R03/B08	A Study of the Application of Evolutionary Computation to Machine Learning	**JINNO Kenya** Faculty of Knowledge Engineering, Department of Information and Communication Engineering, Tokyo City University	**HORIO Yoshihiko**
R03/B09	Study of perceptual, motor, cognitive, and emotional human characteristics towards the understanding of the neural mechanisms of social behavior	**TSUTSUI Ken-Ichiro** Graduate School of Life Sciences, Tohoku University	**SHIOIRI Satoshi**
R03/B10	Measurement of subjective discomfort for VR sickness assessment using core body temperature fluctuation detection	**YUDA Emi** Center for Data-driven Science and Artificial Intelligence, Tohoku University	**KITAMURA Yoshifumi**
R03/B11	Mental imagery processing in people with aphantasia	**TAKAHASHI Junichi** Faculty of Human Development and Culture, Fuskushima University	**SAKAMOTO Shuichi**
R03/B12	Empirical Research on dic Ubiquitous Computing Systems	**ISHIDA Shigemi** Faculty of Information Science and Electrical Engineering, Kyushu University	**KITAGATA Gen**
R02/S01	Establishment for innovative coherent wave technology and its applications	**MIMURA Hidenori** Research Institute of Electronics, Shizuoka University	**YASAKA Hiroshi**
R03/SI	In English: Human sciences with AI technologies	**Su-Ling Yeh** AI and Advanced Robotics Center, Institute Graduate School National Taiwan University	**SHIOIRI Satoshi**
R02/U01	Investigating usage of nonverbal information for online classes	**SHIOIRI Satoshi** Research Institute of Electrical Communication, Tohoku University	**SHIOIRI Satoshi**
R03/U01	The Effects of Network Delay in Ensemble Performance	**TOIDA Koichi** Graduate School of Arts and Science, The University of Tokyo	**YAMAMOTO KOSUKE**
R03/U02	Modeling the Japanese-Taiwanese racial effect in facial expression recognition	**CHEN Chien-Chung** Department of Psychology, National Taiwan University	**Chia-huei Tseng**

5. Symposium organized by the Institute

This Symposium is planned to exchange relevant information on current important topics concerning Electrical Eng., Electrical Communications, Electronic Eng., and Information Eng. Many related researchers inside and outside Tohoku University participate the Symposium and stimulate discussion.

International symposium organized by the Institute（Symposiums held in FY2021）

No	Title	Date
110	2021 Spintronics Workshop on LSI	Jun. 13,2021
111	RIEC International Symposium : The 9th Russia-Japan-USA-Europe Symposium on Fundamental & Applied Problems of Terahertz Devices & Technologies (RJUSE TeraTech-2021)	Nov. 1-4,2021
112	1st Online RIEC International Workshop on Spintronics	Nov. 18,2022
113	RIEC International Symposium on Human-Computer Interaction	Feb. 11,2022
114	The 10th RIEC International Symposium on Brain Functions and Brain Computer	Feb. 18-19,2022
115	The 12th International Workshop on Nanostructures and Nanoelectronics	Mar. 14-15,2022
116	International Symposium on Yotta Informatics	Mar. 17-18,2022
117	6th & 7th CIES Technology Forum	Mar. 22-23,2022

6. Study Groups on Electrical Communication

Study Groups on Electrical Communication are organized to solve scientific and technological problems and to promote research and development through the collaboration of the Research Institute of Electrical Communication, Group of ECEI (Electrical Engineering, Communication Engineering, Electronic Engineering, and Information Engineering) in Graduate Schools of Engineering, Information Sciences, Biomedical Engineering, related scientists and engineers inside and outside Tohoku University. The Study Groups on Electrical Communication consist of 15 Sub-Groups as listed, to deal with specific subjects. Each Sub-Group holds workshops and the abstracts of the workshops are published annually in The Record of Electrical and Communication Engineering Conversazione Tohoku University.

Many scientists and engineers not only from universities but also from government laboratories and industries attend the workshops, present papers, and discuss issues actively. We are pleased to provide information on these activities upon request. Please contact the General Chairman or each Sub-Group Chairman for general information or more specific questions.

Electromagnetic and Optical Waves Engineering	
Chair	Prof. Qiang Chen
Manager	Associate Prof. Keisuke Konno

Acoustic Engineering	
Chair	Prof. Shuichi Sakamoto
Manager	Associate Prof. Takashi Nose

Tohoku Plasma Forum	
Chair	Prof. Toshiro Kaneko
Manager	Prof. Akira Ando

Sendai Seminar on EMC	
Chair	Prof. Masahiro Yamaguchi
Manager	Prof. Masahiro Yamaguchi

Computer Science	
Chair	Prof. Eijiro Sumii
Manager	Associate Prof. Kazutaka Matsuda

Systems Control	
Chair	Prof. Takashi Watanabe
Manager	Associate Prof. Norihiro Sugita

Information-biotronics	
Chair	Prof. Ayumi Hirano
Manager	Associate Prof. Koichiro Miyamoto

Spinics	
Chair	Prof. Kazushi Ishiyama
Manager	Associate Prof. Yasushi Endo
Manager	Associate Prof. Tomoyuki Ogawa

New Paradigm Computing	
Chair	Prof. Masanori Hariyama
Manager	Associate Prof. Masanori Natsui

Ultrasonic Electronics	
Chair	Prof. Hiroshi Kanai
Manager	Associate Prof. Mototaka Arakawa

Brainware	
Chair	Prof. Akio Ishiguro
Manager	Assistant Prof. Kotaro Yasui

Mathematical Physics and its Application to Information Sciences	
Chair	Prof. Kazuyuki Tanaka
Manager	Prof. Masayuki Ohzeki
Manager	Assistant Prof. Manaka Okuyama
Manager	Project Assistant Prof. Madoka Kobayashi

Biocybernetics and Bioinformatics	
Chair	Prof. Satoshi Shioiri
Manager	Associate Prof. Takeshi Obayashi
Manager	Assistant Prof. Yasuhiro Hatori

Nanoelectronics and Spintronics	
Chair	Prof. Shigeo Sato
Manager	Prof. Syunsuke Fukami

7. International Activities

Many of the staff in RIEC contribute to the development of technology and science in the world by serving as editors of referees of international journals or by chairing or programming international conferences. In some fields in electronics, electrical communications, or information engineering RIEC serves as a Center of Excellence (COE), which attracts researchers and students from all over the world every year. Several academic exchange programs with foreign colleges or institutes are in operation.

International academic exchange programs

- University of California, Santa Barbara (U.S.A.)
- University of California (U.S.A.)
- Purdue University (U.S.A.)
- National Taiwan University (Taiwan)
- Swiss Federal Institute of Technology, Lausanne (Swiss)
- The University of York (U.K.)
- National Chiao Tung University (Taiwan)
- The Technische Universität Dresden (Germany)
- Berlin Institute of Technology (Germany)
- National Tsing Hua University (Taiwan)
- Harvard University (U.S.A.)
- Technische Universität München (Germany)
- The University of Kaiserslautern (Germany)
- Johannes Gutenberg University of Mainz (Germany)
- Chemnitz University of Technology (Germany)
- The University of Melbourne (Australia)
- University of Regensburg (Germany)
- Carl von Ossietzky University of Oldenburg (Germany)
- University of Salamanca (Spain)
- St. Petersburg Electrotechnical University (Russia)
- Institute of Physics, Polish Academy of Sciences (Poland)
- IHP-Innovations for High Performance Microelectronics (Germany)
- The Interdisciplinary Center on Nanoscience of Marseille, National Center of Scientific Research (France)
- Institute of Semiconductors, Chinese Academy of Sciences (China)
- WINLAB, Rutgers University (U.S.A.)
- Research and Educational Center "Photonics and Infrared Technology" and Institute of Radio Electronics and Laser Technology, Bauman Moscow State Technical University(BMSTU) (Russia)
- Research Laboratory of Electronics (RLE), Massachusetts Institute of Technology (MIT) (U.S.A.)
- Telecom ParisTech (France)
- Faculty of Physics, M.V.Lomonosov Moscow State University (Russia)
- Center for Artificial Intelligence and Advanced Robotics, National Taiwan University (Taiwan)
- V.G. Mokerov Institute of Ultra High Frequency Semiconductor Electronics of the Russian Academy of Sciences, and Prokhorov General Physics Institute of the Russian Academy of Sciences (Russia)

International journals in which a staff in RIEC participates as an editor

1	Applied Physics Express
2	Auditory Perception and Cognition
3	Bioinspiration & Biomimetics
4	Computer Animation and Virtual Worlds
5	Frontiers in Neuroscience
6	IEEE Transactions on Circuits and Systems I
7	Japanese Journal of Applied Physics
8	Nonlinear Theory and Its Applications, IEICE
9	Scientific Reports
10	Soft Robotics

Recent international conferences programmed by a staff in RIEC

1	10th 2021 IEEE International Conference on Communications, Network, and Satellite (IEEE Comnetsat 2021)
2	11th International Workshop on Nanostructures & Nanoelectronics (IWNN-11)
3	15th International Symposium on Functional and Logic Programming (FLOPS 2020)
4	17th EuroVR International Conference (EuroVR 2020)
5	2020 IEEE International Symposium on Radio- Frequency Integration Technology (RFIT 2020)
6	2020 International Conference on Advanced Technologies for Communications (ATC 2020)
7	2020 International Symposium on Nonlinear Theory and Its Applications (NOLTA2020)
8	26th IEEE Symposium on Computers and Communications (ISCC 2021)
9	29th International Workshop on Post Binary ULSI Systems
10	39th ACM CHI Conference on Human Factors in Computing Systems (CHI 2021)
11	50th IEEE International Symposium on Multiple-Valued Logic (ISMVL 2020)
12	7th International Workshop on Rewriting Techniques for Program Transformations and Evaluation (WPTE 2020)
13	IEEE Asia Pacific Conference on Wireless and Mobile 2021 (APWiMob 2021)
14	IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD 2021)
15	IEEE The International Magnetics Conference (INTERMAG 2020)
16	IEEE The International Magnetics Conference (INTERMAG 2021)
17	IEEE The Magnetic Recording Conference (TMRC 2020)
18	IEEE The Magnetic Recording Conference (TMRC 2021)
19	IEEE/ACM International Symposium on Quality of Service 2021 (IwQoS 2021)
20	International Symposium on Adaptive Motion of Animals and Machines 2021, Program committee
21	INTERNATIONAL TELETRAFFIC CONGRESS ITC 32
22	The 11th International Conference on ICT Convergence (ICTC 2020)
23	The 2020 IEEE 5G World Forum (5GWF'20)
24	The 2021 IEEE Global Communications Conference (GLOBECOM 2021)
25	The 2021 IEEE Wireless Communications and Networking Conference (WCNC 2021)

26	The 2021 International Workshop on Pervasive Information Flow (PerFlow'21)
27	The 2nd International Symposium on Designing Human-Centric IoT Society
28	The 35th International Conference on Information Networking (ICOIN 2021)
29	The 65th Annual Conference on Magnetism and Magnetic Materials (MMM 2020)
30	The 8th International Conference on Information and Communication Technology (ICoICT 2020)
31	The 9th RIEC International Symposium on Brain Functions and Brain Computer (9th BFBC)
32	The Eighth International Symposium on Computing and Networking (CANDAR'20)
33	The IEEE International Conference on Communications (ICC 2021)
34	The Symposium on Emerging Topics in Computing and Communications (SETCAC'20)

8. Periodicals Published by the Institute

The Institute publishes the following two periodicals to inform readers on recent research results of the Institute.

1. The Record of Electrical and Communication Engineering Conversazione Tohoku University

This journal aims at providing an opportunity to publish research results of the Institute as well as the result of the Graduate Schools of Engineering, Information Sciences, Biomedical Engineering. Since the journal also aims at publishing general research activities of the Institute and of the Graduate Schools such as records of the final lectures of retiring professors, records of the Institute Symposium, and reviews.

The name of the Journal `Conversazione´ is attributable to the `Tuesday Conversazione´ at the Department of Electrical Engineering, which had been held once a week on Tuesday since around 1920. Minutes of the meetings had been distributed to researchers outside of the University via various routes and therefore some of them had been referred to as `Records of Tuesday Electrical Engineering Conversazione Tohoku University´ with the result that they came to be treated as official publications. Though the meeting was once interrupted by World War Two, it was restarted in 1947. In 1952, the publication of the records was succeeded by the Institute and the records have been published as periodicals, two times a year recently, since No. 1 Vol. 21 was published in July, 1952.

2. The Annual Report of Research Activity at the Research Institute of Electrical Communication, Tohoku University

Published annually since 1995. This report details the activities of each research division and research facility. Also included are reports on nation-wide cooperative research projects, international symposium and seminars organized by members of RIEC, and the reports and evaluation on the RIEC advisory board members. English version is also available since 2007.

3. RIEC News

As a part of RIEC's publication service, "RIEC News" is published.
With the 75th anniversary of the establishment of RIEC, RIEC News introduces cutting-edge's research and the vision of the future from RIEC's contributions to the progression of science and technology in Japan. RIEC News was first launched in March 2011. Every issue introduces special topics such as large scale projects and Specially-Promoted Research, etc. RIEC News also includes current information about each laboratory and center, all kinds of RIEC events, research exchange meetings, laboratories open to the public (RIEC Open Day), etc. English version was also launched in March 2014. Further, RIEC News offers a notification service by mail whenever a new issue is released and an electronic version of every issue published so far can be downloaded by following the link below.
http://www.riec.tohoku.ac.jp/riecnews/

With the 26th issue of RIEC News, it has finished multi-monthly publication style as before. From April 2020, in order to bring you the latest research results and event information as quickly as possible, RIEC News was renewed to a new web-based publication style. The new RIEC Newsweb is published by the following link.
http://www.riec.tohoku.ac.jp/riecpr/

9. Staff, Budget

1. Faculty & Staff

as of May 1, 2021

Professors	22
Associate Professors	19
Assistant Professors	19
Research Fellows	7
Specially Appointed Professors	2
Specially Appointed Assistant Professors	2
Administrative Staff（Including Limited Regular Employees）	33
Technical Staff（Including Limited Regular Employees）	16
Total	120

2. Researchers (FY2021)

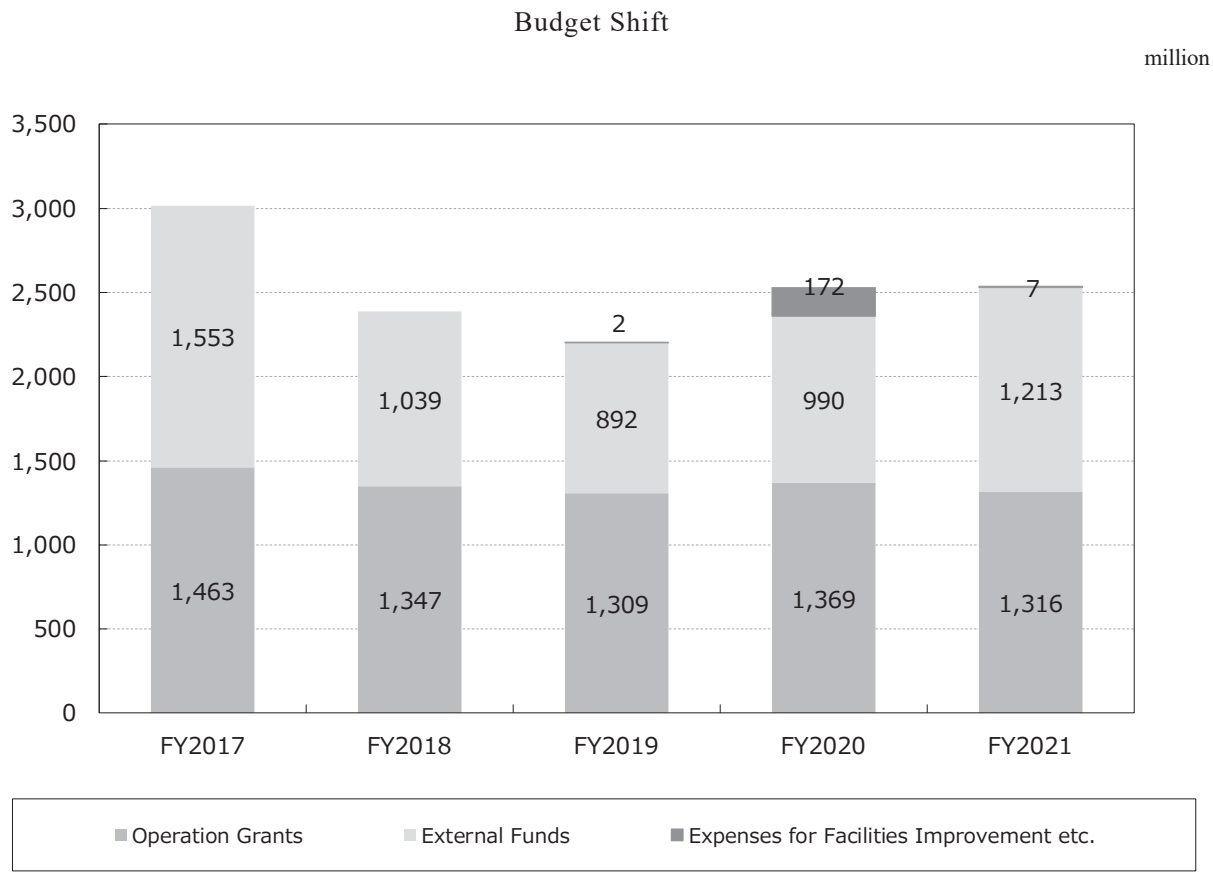
Foreign Researchers	Visiting Professors	0
	Visiting Asociate Professors	0
Cooperative Researchers of Private Company etc		10
JSPS Research Fellowship for Young Scientists		8
JSPS Postdoctral Fellowship for Overseas Researchers		2
Invitation Fellowship for Research in Japan		0
Contract Researchers		1
Contract Trainees		1
Total		22

3. Students

as of May 1, 2021

	School of Engineering	Graduate School of Information Science	Graduate School of Biomedical Engineering	RIEC	Total
Undergraduate Students	60 (0)				60 (0)
Master Course Students	96 (9)	42 (5)	8		146 (14)
Doctor Course Students	12 (6)	10 (6)	4		26 (12)
Institute Reserch Students				1 (1)	1 (1)
Total	168 (15)	52 (11)	12	1 (1)	233 (27)

4. Budget



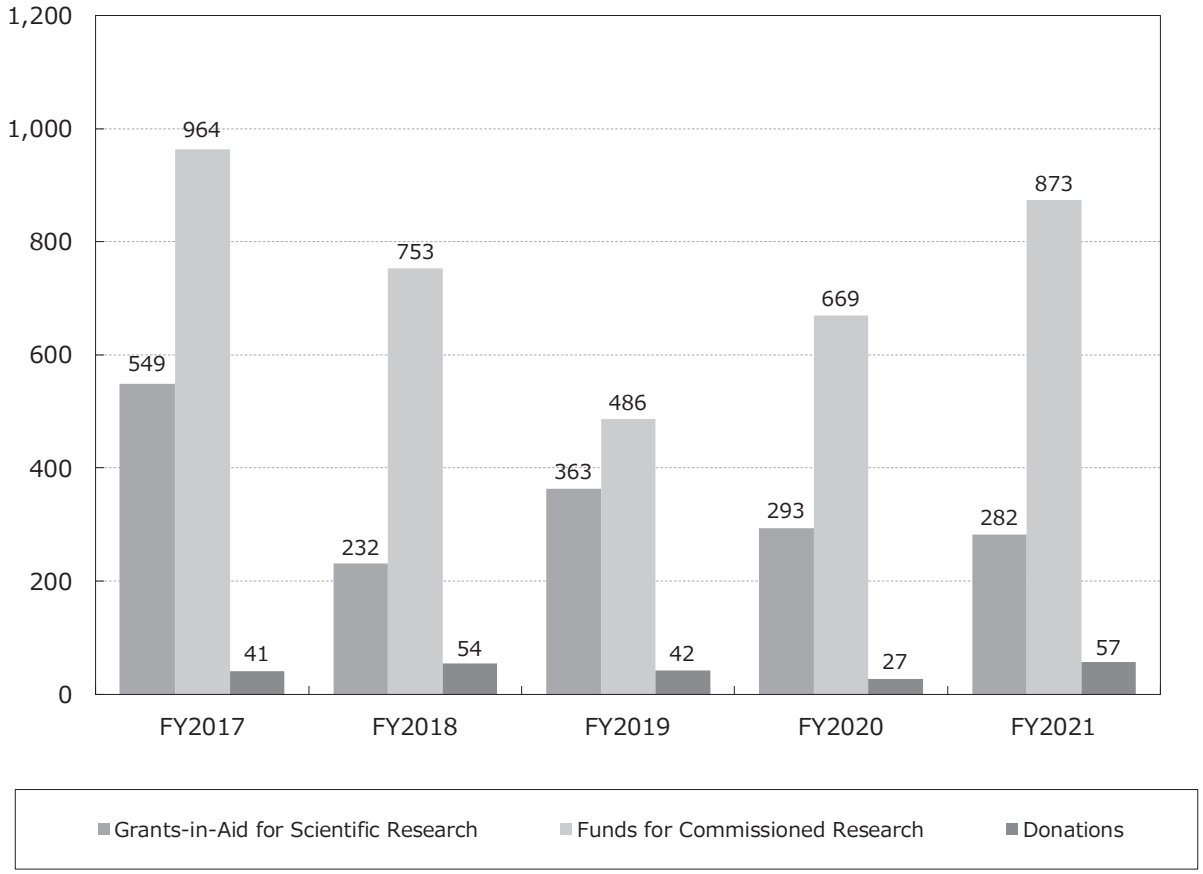
■ Budget Summary

thousand yen

Categories		FY2017	FY2018	FY2019	FY2020	FY2021
Operation Grants	Personnel Expenses	835,904	790,118	742,128	801,695	744,591
	Non-Personnel Expenses	626,824	556,937	566,533	567,249	571,737
Operation Grants Total		1,462,728	1,347,055	1,308,661	1,368,944	1,316,328
External Funds	Grants-in-Aid for Scientific Research	549,034	231,643	363,325	293,404	282,400
	Funds for Commissioned Research	963,585	753,391	486,053	669,454	873,456
	Donations	40,541	54,344	42,436	27,200	57,422
	Indirect Expenses	220,733	134,311	155,852	172,874	234,487
External Funds Total		1,553,160	1,039,378	891,814	990,058	1,213,278
Expenses for Reconstruction		0	0	1,936	172,477	6,732
Expenses for Relocation		0	0	0	0	0
Expenses for Facilities Improvement		0	0	0	0	0
Expenses for Facilities Improvement etc. Total		0	0	1,936	172,477	6,732
Total		3,015,888	2,386,433	2,202,411	2,531,479	2,536,338

External Funds

million yen



■ External Funds

thousand yen

Categories	FY2017	FY2018	FY2019	FY2020	FY2021
Grants-in-Aid for Scientific Research	549,034	231,643	363,325	293,404	282,400
Funds for Commissioned Research	963,585	753,391	486,053	669,454	873,456
Donations	40,541	54,344	42,436	27,200	57,422
Total	1,553,160	1,039,378	891,814	990,058	1,213,278

Annual Report 2021

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