Annual Report 2020

Research Institute of Electrical Communication
Tohoku University

1. Introduction

It is the mission of 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 a 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 enrich 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 as a Joint Usage/Research Center for collaborative research in information science and technology. The current fiscal year marks the fifth year of the program's second term. 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

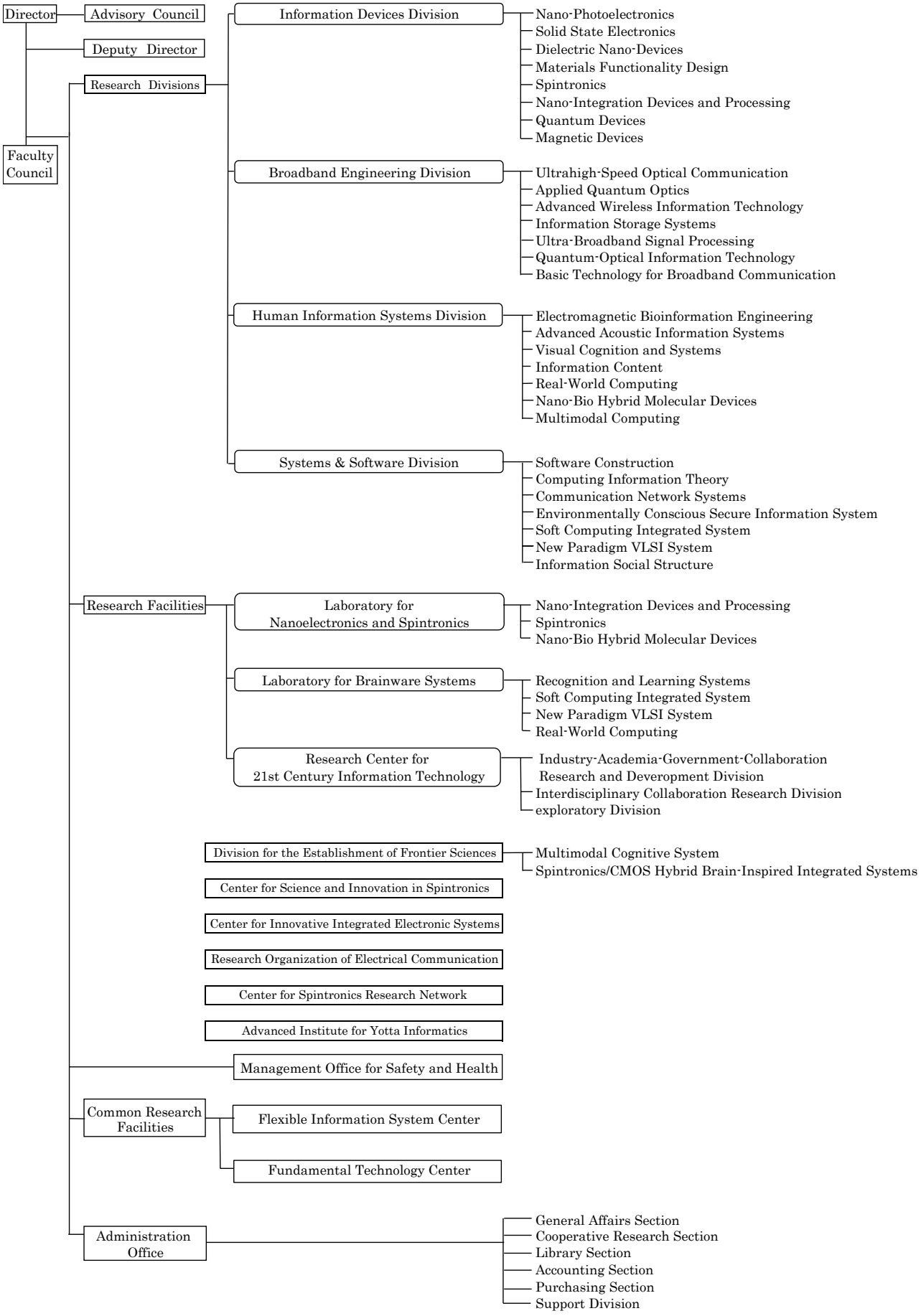
activities, including the research conducted by each of our departments and laboratories, collaborative research projects, international activities, social contributions, the RIEC symposia, activities of the engineering research association, and RIEC lectures. The bibliography section also includes data 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.

July 1, 2021

Satoshi Shioiri
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 2020 are described in the following pages.

Nano-Photoelectronics

Exploring optical and electronic properties of nanometer-sized structures and their applications in photoelectronic devices

Nanophotoelectronics Yoichi Uehara, Professor
Nano photomolecular electronics Satoshi Katano, Associate Professor

[Research Target and Activities]

Our main interest lies in studying the physical and chemical phenomena that take place in nanometer-scale regions and their applications in nanophotoelectronic devices. The summary of our achievements is as follows.

(1) Mechanism of the vibrational structure appearing in the STM light emission (STMLE) spectrum

We clarified the appearance of periodic fine structures in the STMLE spectrum. It was found that when the tip-sample gap length is modulated by the vibrations of sample, the tunnel current is modulated. Calculations were performed for Ni(110)-(1×2)H, AgNP-HOPG and AuNP-Al_2O_3 systems, which reproduce experimental results.

(2) Finite difference time domain analysis of STMLE spectrum

We found that the vibrational energies of individual adsorbed species are determined experimentally from the step structure appearing near the quantum cutoff in the STMLE spectrum. We elucidated the mechanism that enhances the vibration-induced structure ratio using FDTD method. Nanostructures existing in the tip-surface junction enhance the local electric field, leading to the increase of the vibration-induced structure ratio.

(3) Microscopic structural control of nanocarbon

Controlling the adsorption structure of graphene oxide (GO) on the substrate is an important issue for applications such as biosensors and optical elements. In this study, we investigated the control of the adsorption structure of GO by using hydrophilic (C8H16SH) and hydrophobic (C10F17SH) monolayers on Au(111).

(4) Control of nanoscale photoelectron properties using metal nanoparticle array

A silver nanocube (AgNC) has been attracting many attentions as a new plasmonic material. In this study, we conducted on the thermal reactions of PVP coated on the AgNC monolayer array. We found the sintering between AgNCs occurs at a temperature lower than the melting point of AgNC, leading to the deactivation of SERS.

(5) Nanoscale growth mechanism of atomic insulating layer

We have studied the thermal diffusion of the NaCl thin film formed on the Au (111) surface by continuous STM observations. We found that the growth of NaCl film proceeds via the monoatomic step of the Au substrate.

[Staff]

Professor	Yoichi Uehara, Dr.
Associate Professor	Satoshi Katano, Dr.

[Profile]

Dr. Yoichi Uehara obtained his D. Eng. degree from the Department of Engineering, University of Osaka prefecture in 1986, after which, he was initially appointed as an Assistant Professor at the Research Institute of Electrical Communication, Tohoku University. He eventually became a Full Professor at the institute in 2005. Dr. Uehara has worked on three main surface physics problems at Tohoku University: (1) light emission from metal-insulator-metal and metal-oxide-semiconductor (MOS) tunnel junctions, (2) low-energy electron spectroscopy, and (3) light emission spectroscopy of STM.

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. S. Katano, and Y. Uehara, "In situ Observation of Atomic Scale Growth of NaCl Thin Crystal on Au(111) by Scanning Tunneling Microscopy", *J. Phys. Chem. C*, **124**, 20184–20192 (2020).
2. S. Katano, T. Iwahori, R. Yamasaki, A. Mizuno, A. Ono, and Y. Uehara, "Localized surface plasmon-induced vibrational excitations in the surface-enhanced Raman scattering using two-dimensional array of silver nanocubes", *J. Appl. Phys.*, **127**, 185301_1-9 (2020).

Solid State Electronics Laboratory

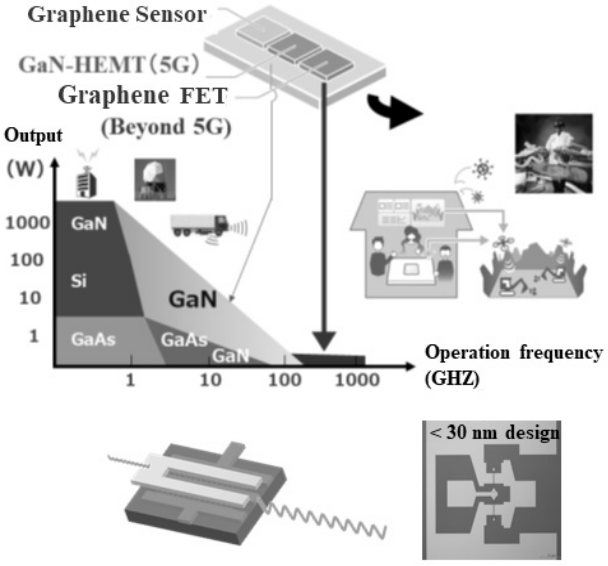
Creating Beyond 5G devices with low environmental load

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 FY2020, we succeeded in developing a novel method of producing a wafer-scale ultrahigh quality graphene with an affordable cost, down to 1/00 cost, and graphene transistors operating in THz frequencies. This technology attracts much attention from major companies, such as Shinetsu chemicals and IBM. Furthermore, we developed spatiotemporal operando x-ray spectroscopy, enabling spatio-temporally examining electronic states of advanced devices.



Next-generation devices with low environmental load to accomplish SDGs

[Staff]

Associate Professor : Hirokazu Fukidome, Dr.
Research 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] P. Padmanabhan, S. Boubanga-Tombet, H. Fukidome, T. Otsuji, and R. P. Prasankumar, "A graphene-based magnetoplasmonic metasurface for actively tunable transmission and polarization rotation at terahertz frequencies," Appl. Phys. Lett., Vol. 116, No. 22, pp. 221107-1-221107-4, 2020

[2] K. Omika, K. Takahashi, A. Yasui, T. Ohkochi, H. Osawa, T. Kouchi, Y. Tateno, M. Suemitsu, H. Fukidome, "Dynamics of Surface Electron Trapping of a GaN-based Transistors Revealed by Spatiotemporally-Resolved X-ray Spectroscopy," Appl. Phys. Lett., Vol. 117, No. 17, pp. 171605-1-171605-6, 2020

[3] N. Endoh, S. Akiyama, K. Tashima, K. Suwa, T. Kamogawa, R. Kohama, K. Funakubo, S. Konishi, H. Mogi, M. Kawahara, M. Kawai, Y. Kubota, T. Ohkochi, M. Kotsugi, K. Horiba, H. Kumigashira, M. Suemitsu, I. Watanabe and H. Fukidome, "High-Quality Few-Layer Graphene on Single-Crystalline SiC thin film Grown on Affordable Wafer for Device Applications," Nanomaterials, Vo. 11, No. 2, pp. 392-1-392-13, 2021 **Editor's choice**

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.

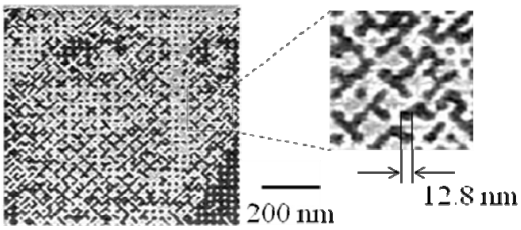


Fig.1 Digital bit data written on ferroelectric single crystal with the areal recording density of 4 Tbit/inch^2.

Major achievements of studies in 2020 are as follows: (1) We revealed a microscopic mechanism of potential induced degradation (PID) arising in monocrystalline Si solar cells and also showed SNDM can visualize p- to n-type transition in atomically thin MoS_2 layers on SiO_2 (2) We showed SNDM can resolve carrier distribution of floating gates and channel structures in modern 3D flash memory cells with less than 1.9 nm resolution (3) We proposed a novel local CV mapping method and demonstrated that it permits the real-space and nanoscale imaging of ferroelectric domain switching dynamics.

[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. Cho, S. Jonai, and A. Masuda, Appl. Phys. Lett., Vol. 116, p. 182107, 2020.
[2] K. Yamasue and Y. Cho, J. Appl. Phys. 128, pp.074301, 2020.
[3] Y. Hiranaga, T. Mimura, T. Shimizu, H. Funakubo and Y. Cho, J. Appl. Phys. 128, 244105, 2020.

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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 machine learning techniques.
Our research activities in FY 2020 are as follows:

(1) Transport properties at finite temperatures

We developed an *ab initio* method to simulate the temperature dependence of electronic structure and transport properties at finite temperatures, considering the effects of lattice vibrations, spin fluctuations, and the atomic disorder within the coherent potential approximation. The temperature dependence of resistivity experimentally observed for Co_2MnSi can be well reproduced by the present method [2].

(2) Machine learning for Heusler alloy/MgO junctions

We performed first-principle calculations for quaternary Heusler alloy/MgO junctions (Fig. 1), and recorded physical properties such as magnetic stiffness in a database. We constructed a model predicting physical properties at the interfaced with the aid of machine learning. The model can predict the interfacial magnetic stiffness of junctions in high accuracy, i.e. the correlation coefficient of about 0.9.

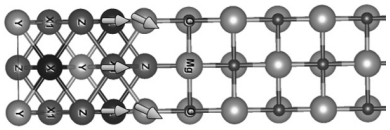


Fig. 1: The structure of a Heusler alloy/MgO junction.

(3) Dense metallic hydrides

New metallic phases of dense SiH_2 and SiH_3 are predicted by using *ab initio* methods. The superconducting transition temperatures (T_c) of the SiH_2 and SiH_3 phases are estimated to be 83 K at 400 GPa and 88 K at 450 GPa, respectively. These T_c values are much higher than those of SiH_4 at corresponding pressures, suggesting that high-T_c superconductivity is more likely to be achieved in the subhydrides rather than in SiH_4.

[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] M. Tsujikawa, Y. Mitsuhashi, and M. Shirai, "Theoretical design of tetragonal rare-earth-free alloys with high magnetisation and high magnetic anisotropy," Jpn. J. Appl. Phys., Vol. 59, Article no. 055506, pp. 1-5, 2020
[2] H. Shinya, *et al.*, "First-principles calculations of finite temperature electronic structures and transport properties of Heusler alloy Co_2MnSi," Appl. Phys. Lett., Vol. 117, Article no. 042402, pp. 1-5, 2020
[3] T. Roy, M. Tsujikawa, and M. Shirai, "*Ab initio* study of electronic and magnetic properties of Mn_2RuZ/MgO (001) heterostructures (Z = Al, Ge)," J. Phys.: Condens. Matter, Vol. 33, Article no. 145505, pp. 1-9, 2021

Spintronics

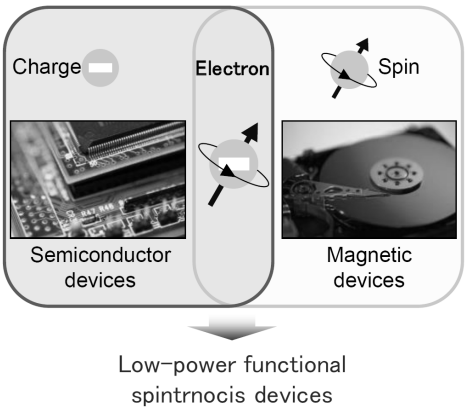
Advanced technology for spintronics-based devices

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 tecnologies.

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), and Marubun Research Encouragement Award (2021).

[Papers]

[1] J. Llandro, D. M. Love, A. KovácsJan, J. Caron, K. N. Vyas, A. Kákay, R. Salikhov, K. Lenz, J. Fassbender, M. R. J. Scherer, C. Cimorra, U. Steiner, C. H. W. Barnes, R. E. Dunin-Borkowski, S. Fukami, and H. Ohno, "Visualizing Magnetic Structure in 3D Nanoscale Ni–Fe Gyroid Networks," Nano Letters **20**, 3642-3650 (2020).
[2] B. Jinnai, J. Igarashi, K. Watanabe, T. Funatsu, H. Sato, S. Fukami, and H. Ohno, "High-Performance Shape-Anisotropy Magnetic Tunnel Junctions down to 2.3 nm," IEEE International Electron Devices Meeting (IEDM2020), 24.6.1, Online, 2020/12/12-18.
[3] K. Hayakawa, S. Kanai, T. Funatsu, J. Igarashi, B. Jinnai, W. A. Borders, H. Ohno, and S. Fukami, "Nanosecond Random Telegraph Noise in In-Plane Magnetic Tunnel Junctions," Physical Review Letters **126**, 117202 (2021).

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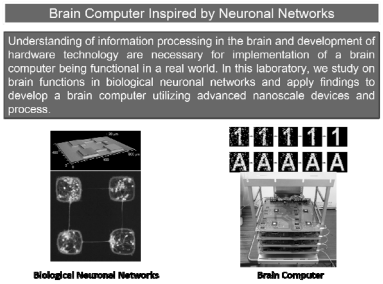
Nano-Integration Devices and Processing

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 developed a spiking neuron circuit that can reproduce various neuron pulses with ultra-low power consumption. We confirmed by numerical simulations that the power consumption of our analog MOS circuit is less than 10 nW when it operates in the weak inversion region. (2) Toward the realization of Si crystal structure transformation into penta-silicene, we performed selective etching of Ge in a Ge/ultrathin Si/Ge heterostructure in which a 5 nm-thick Si film was sandwiched by Ge. We confirmed that micrometer-scale isolated Si films were obtained, which indicates that a crosslinked structure of Si can be formed by this method. (3) We used computational simulation to show that the two biologically plausible mechanisms, i.e., modular network architecture and Hough transformation, help improve the computational efficiency and robustness against system damage in a reservoir computing model for image recognition.



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. Moriya, H. Yamamoto, A. Hirano-Iwata, S. Kubota, S. Sato, “Modular Networks of Spiking Neurons for Applications in Time-Series Information Processing”, Nonlinear Theory and Its Applications, IEICE, 11, 590-600, 2020.

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 2020 are the following.

(1) Development of high-speed electric microprobes

We developed the local electronic sensors which can directly access local electronic states in nanostructures utilizing semiconductor quantum dots. We improved the performance by high-frequency measurement techniques and data informatics approaches [1].

(2) Measurement of local electronic states in nanostructures

We measured local electronic and spin states in semiconductor nanostructures utilizing sensitive electronic sensors. We revealed the detail of local electronic states in new materials and quantum dot devices [2, 3].

(3) Development of quantum devices

We studied semiconductor quantum bits for future quantum information processing. We conducted experiments on quantum bit operations and developed techniques for scale-up of quantum systems.

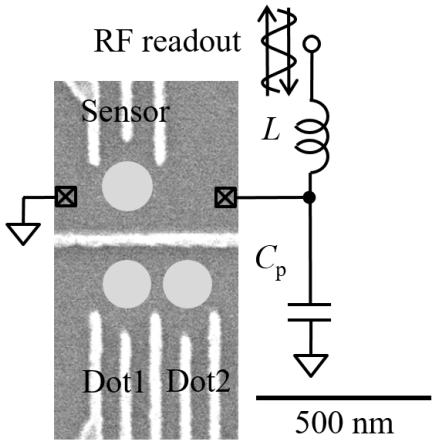


Figure: Scanning electron micrograph of a nanostructure device

[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] M. Shinozaki, Y. Muto, T. Kitada, T. Nakajima, M. R. Delbecq, J. Yoneda, K. Takeda, A. Noiri, T. Ito, A. Ludwig, A. D. Wieck, S. Tarucha, and T. Otsuka, "Gate voltage dependence of noise distribution in radio-frequency reflectometry in gallium arsenide quantum dots", Applied Physics Express 14, 035002 (2021).

[2] T. Otsuka, T. Abe, T. Kitada, N. Ito, T. Tanaka, and K. Nakahara, "Formation of quantum dots in GaN/AlGaN FETs", Scientific Reports 10, 15421 (2020).

[3] T. Kitada, M. Seo, T. Abe, M. Shinozaki, N. Sato, T. Aizawa, Y. Muto, T. Kaneko, T. Kato, and T. Otsuka, "Quantum Dots in plasma CVD Graphene Nanoribbons", International Symposium for The Core Research Clusters for Materials Science and Spintronics, Online, Feb. 24, 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 10 ch WDM transmission of 1.28 Tbit/s Nyquist pulses with a total capacity of 12.8 Tbit/s over 1500 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 with an injection-locked carrier frequency converter for precise down-conversion of the optical QAM frequency to 61 GHz. 64 Gbit/s data were successfully transmitted over 10 km through an optical fiber and 6 m wirelessly.

(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 high speed semiconductor laser introducing hybrid modulation scheme was being continued. It was confirmed experimentally that the hybrid modulation semiconductor laser source we proposed had wide intrinsic small signal bandwidth of more than 80 GHz by using novel optical measurement system we proposed. Furthermore the study on compact and narrow linewidth semiconductor laser sources was also being proceeded by applying the optical negative feedback technology we proposed. A compact optical filter with Si waveguide was designed to enlarge a frequency discrimination efficiency and enlarge a feedback gain of the negative feedback system. It was confirmed that the lasing spectral linewidth was reduced to 50 kHz by hybrid integration of the fabricated optical filter based on the design to a single mode semiconductor laser.

(3) Advanced Wireless Information Technology

We are actively engaged in research work on dependable wireless information 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., signal processing, RF/Mixed-signal device, antenna, MODEM, and network technologies. This year, we have investigated (1) uplink Non-Orthogonal Multiple Access (NOMA) in the consideration of the imperfections of synchronization for wireless IoT and (2) fully digital beam forming antenna fed by direct digital RF transmitters with 10GbE optical fiber link.

(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 microwave-assisted magnetic recording (MAMR) with a spin-torque oscillator (STO) and heat assisted magnetic recording (HAMR) using near-field light 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 testbed visualization analytics platform for brain neuro structures with unified PB-class storage and computation functions. The data access performance for the 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, for the realization of

photonics-electronics convergence devices, we developed a novel device that introduces a photoabsorption structure of a unitraveling-carrier photodiode into an InGaAs-channel high-electron-mobility transistor and successfully demonstrated the gain enhancement of the frequency down-conversion from 1.5-μm optical data signal to millimeter-wave data signal by one order of magnitude by reducing the active area size of the photodiode.

(6) Quantum-Optical Information Technology

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

In 2020, we have achieved (1) spectral characterization of photon-pair sources via classical sum-frequency generation, (2) development of high Q mg-scale monolithic pendulum for quantum-limited gravity measurement, (3) development of photoinduced Kerr rotation spectroscopy for microscopic spin systems using heterodyne detection, and (4) Optical detection of nano-particle characteristics on a nanofiber and optical transport of sub-micron lipid vesicles along a 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]

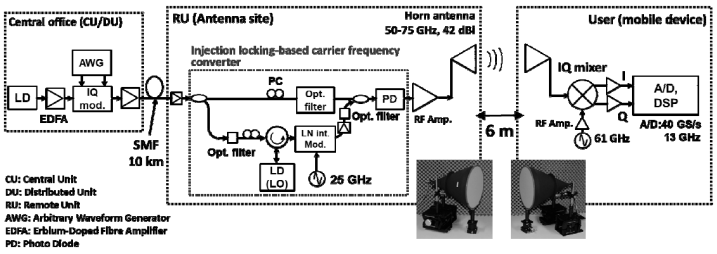

Fig. 1. 64 Gbit/s, 256 QAM coherently-linked optical and wireless transmission in 61 GHz band using injection-locked carrier frequency converter

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 10 ch WDM transmission of 1.28 Tbit/s Nyquist pulses with a total capacity of 12.8 Tbit/s over 1500 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 for next-generation RAN (Fig. 1). An injection-locked carrier frequency converter enabled the precise down-conversion of the optical QAM frequency to 61 GHz. 64 Gbit/s data were successfully transmitted over 10 km through an optical fiber and 6 m wirelessly.

[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 Japan Society for the Promotion of Science 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. Hirooka, M. Yoshida, and M. Nakazawa, "64 Gbit/s, 256 QAM coherently-linked optical and wireless transmission in 61 GHz band using novel injection-locked carrier frequency converter," ECOC 2020, Th1G-7, Dec. (2020).
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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 experimentally that the hybrid modulation semiconductor laser source we proposed had wide intrinsic small signal bandwidth of more than 80 GHz. Furthermore the study on compact and narrow linewidth (less than 50 kHz) semiconductor laser sources is also being proceeded by applying the optical negative feedback technology we proposed.

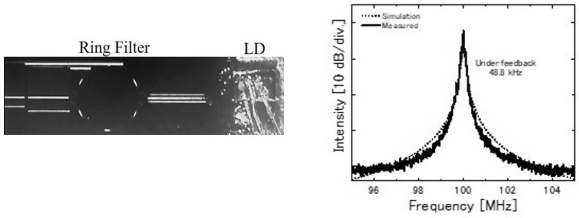

Photo of optical negative feedback laser source composed of single mode laser diode and integrated Si waveguide ring filter (left), and its lasing spectrum (right).

[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] M. Kanno, N. Yokota, and **H. Yasaka**, "Measurement of Intrinsic Modulation Bandwidth of Hybrid Modulation Laser," IEEE Photonics Technology Letters, vol. 32, No. 13, pp. 839-842, 2020. (June) / DOI 10.1109/LPT.2020.2993797

[2] N. Yokota, H. Kiuchi, and **H. Yasaka**, "Role of modulation bandwidth in narrow spectral linewidth semiconductor lasers under optical negative feedback," Japanese Journal of Applied Physics, vol. 59, No. 10, pp. 102001-1-10, 2020. (Oct.) / DOI 10.35848/1347-4065/abb39d

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Advanced Wireless Information Technology

For realization of the next generation mobile network

Advanced Wireless Information Technology **Noriharu Suematsu, Professor**
Advanced Wireless Network Technology **Suguru Kameda, Associate Professor**

[Research Target and Activities]

Toward the realization of a ubiquitous and broad-band wireless network, we are actively engaged in the research work on dependable and low power consumption advanced wireless IT. We cover the whole technical fields from the lower to higher layers, i.e., signal processing, RF/Mixed signal device, antenna, MODEM and network technologies.

We have developed load balancing method using route estimation of mobile terminal. We have also developed RF-IC and modules like sample-hold circuit for high speed and low power wireless communication system.

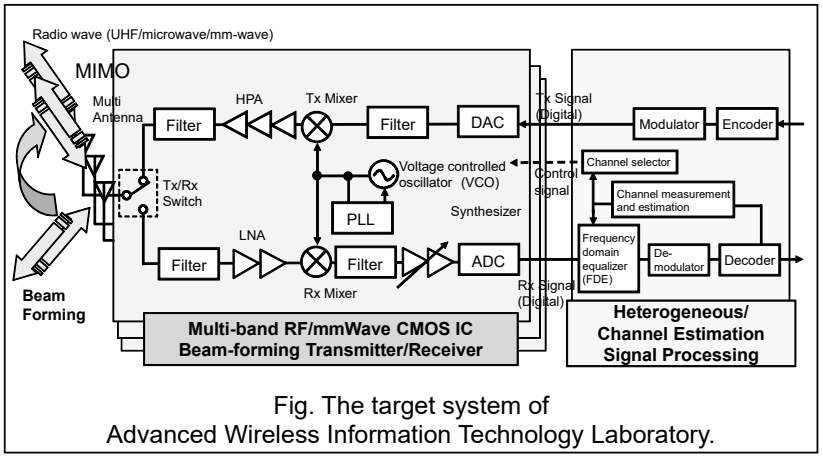

Fig. The target system of
Advanced Wireless Information Technology Laboratory.

[Staff]

Professor: Noriharu Suematsu, Ph. D
Associate Professor: Suguru Kameda, Ph. D
Assistant Professor: Mizuki Motoyoshi, 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

Suguru Kameda received the B.S., M.S. and Ph.D. degrees in Electronics Engineering from Tohoku University in 1997, 1999 and 2001, respectively. From 2001, he was an assistant professor of the RIEC. From 2012, he has been currently an associate professor.

[Papers]

[1] M. Motoyoshi, S. Kameda, N. Suematsu, "Novel Dual-Band Wireless Communication System for Medical usage," 2020 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), pp. 130-132, Sep. 2020.
[2] B. Dang, M. Motoyoshi, J. Xu, H. Sato, S. Kameda, Q. Chen, N. Suematsu, "In-body/Out-body Dual-Use Miniaturized RFID Tag System Using 920MHz/5.02GHz Bands," 2020 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), pp. 148-150, Sep. 2020.
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Information Storage System Laboratory

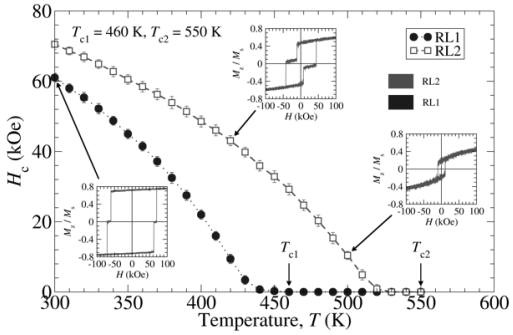
High Density and High Speed Energy Assisted Magnetic Recording, and Computational Storage System Research

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 both microwave-assisted magnetic recording (MAMR) and heat-assisted magnetic recording (HAMR), with the aim of doubling the storage capacity. Using MAMR, it is possible to record data on a medium consisting of multiple, discrete storage layers by utilizing storage layers with different ferromagnetic resonance frequencies. Optimization of recording medium properties and recording conditions using the microwave magnetic field generated by a spin-torque oscillator has been studied [1,2]. A HAMR system has also shown the potential to record data on media with different Curie temperatures [3]. We have constructed a testbed visualization analytics platform for brain neuro structures with unified PB-class storage and computation functions. Computation based on the Xeon-CPU/GPU and unified storage nodes enabled the three-dimensional visualization of neuron structures captured by fluorescent microscopy.



Thermal Properties of dual MAMR media

[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] W. Saito, S. Greaves, Y. Tanaka, “Investigation of selective dual-layer recording only using spin torque oscillator”, Trans. Mag. Soc. Jpn. 4, p1-4, 2020
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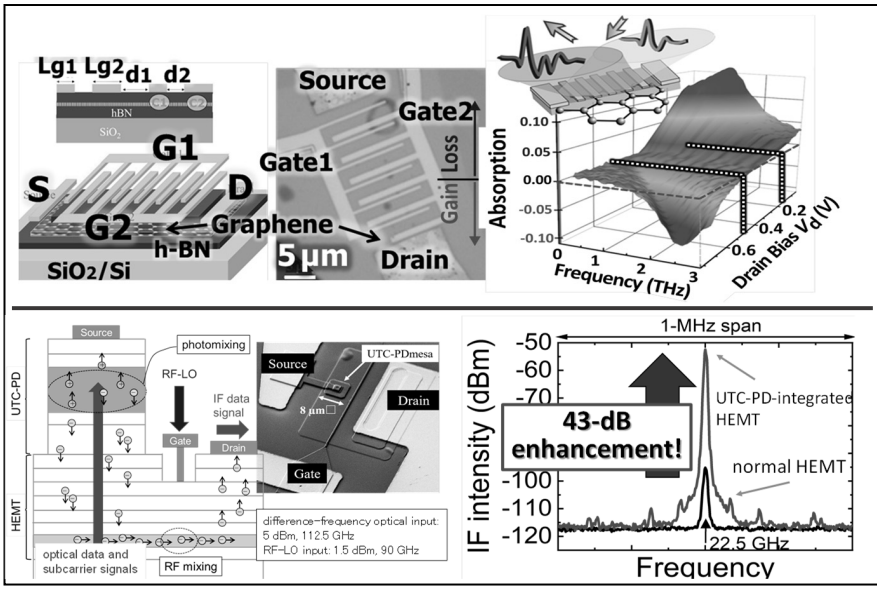
[3] Hikaru Yamane, Simon on Dual Structure Bit Patterned Media”, IEEE Trans. Magn., Vol. 57, No. 2, 2021

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: a cross-sectional structural drawing and SEM image of a UTC-PD-integrated-HEMT for the optical-to-wireless carrier frequency down-conversion and comparison of output intensities of down-converted IF signals at 22.5 GHz from 1.5-μm optical signals using a normal HEMT and the UTC-PD-integrated HEMT.

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, for the realization of photonics-electronics convergence devices, we developed a novel device that introduces a photoabsorption structure of a unitraveling-carrier photodiode into an InGaAs-channel high-electron-mobility transistor and successfully demonstrated a giant gain enhancement of the frequency down-conversion from 1.5-μm optical-wave to millimeter-wave data signal by four orders of magnitude by reducing the active area size of the photodiode.

[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] A. Satou, Y. Omori, K. Nishimura, T. Hosotani, K. Iwatsuki, T. Suemitsu, and T. Otsuji, J. Lightwave Technol., vol. 39(10), pp. 3341-3349, Feb. 2021.
[2] S. Boubanga-Tombet, W. Knap, D. Yadav, A. Satou, D.B. But, V.V. Popov, I.V. Gorbenko, V. Kachorovskii, and T. Otsuji, Phys. Rev. X, vol. 10(3), pp. 031004-1-19, July 2020.
[3] V. Ryzhii, T. Otsuji, and M.S. Shur, Appl. Phys. Lett., vol. 116, pp. 140501-1-6, Apr. 2020. (invited, perspective)

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Quantum-Optical Information Technology

Development of optoelectronic devices for quantum information and communication technology

Quantum-Optical Information Technology: Keiichi Edamatsu, Professor
Quantum Laser Spectroscopy: Yasuyoshi Mitsumori, Associate professor

[Research Target and Activities]

Our goal is to develop quantum information devices utilizing quantum interaction between photons and electrons in solids. In 2020, we have achieved (1) spectral characterization of photon-pair sources via classical sum-frequency generation, (2) development of high Q mg-scale monolithic pendulum for quantum-limited gravity measurement, (3) development of photoinduced Kerr rotation spectroscopy for microscopic spin systems using heterodyne detection, and (4) Optical detection of nano-particle characteristics on a nanofiber and optical transport of sub-micron lipid vesicles along a nanofiber.

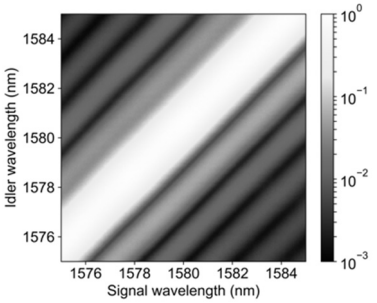

Fig. 1. Example joint spectrum of a photon-pair source measured via classical sum-frequency generation.

[Staff]

Professor: Keiichi Edamatsu, Dr.
Associate Professor: Yasuyoshi Mitsumori, 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.

Yasuyoshi Mitsumori received B.S., M.S. and D.S. degrees in Applied Physics from Tokyo Institute of Technology. He was a Research Fellow of the Japan Society for the Promotion of Science, a Researcher in NTT Basic Research Laboratories, a Postdoctoral Fellow in Tokyo Institute of Technology, a Postdoctoral Fellow in Communications Research Laboratory, a Research Associate in Research Institute of Electrical Communication, Tohoku University.

[Papers]

[1] S.B. Cataño-Lopez, J.G. Santiago-Condori, K. Edamatsu, N. Matsumoto, "High Q mg-scale monolithic pendulum for quantum-limited gravity measurements", Phys. Rev. Lett. **124**, 2221102/1-6 (2020).
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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 microvibration measuring system, we worked on the fabrication of high sensitive strain sensors on a Si wafer and the design of detection circuits with ultra-low noise. The obtained proto-type system shows extra-high sensitivity compare with the commercial products. On the work of high frequency magnetic field measuring system, we have succeeded to measure up to 6GHz magnetic field by our proposed system. This system could visualize the high-frequency field distribution of the circuits. 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 how humans extract target sound from distractor sounds by using auditory selective attention. In this fiscal year, the effect of auditory selective attention in the spatial domain was investigated. We observed the effect of auditory selective attention when the listeners continuously directed their attention to a specific direction. Moreover, this effect depended on the listening tasks the listeners were doing. In addition, we developed advanced acoustic systems, such as 3D virtual auditory displays, sound acquisition and presentation systems. We proposed sound field synthesis method using distributed spherical microphone array based on spherical harmonic analysis.

(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 investigated the contribution of slow- and fast-motion mechanisms to global motion using motion aftereffect (MAE), and found large contribution of the slow-motion mechanism and little or no contribution of the fast-motion mechanism. These results suggest that the human visual system multiple motion processes specialized different stimulus conditions. Secondly, we interviewed performers and spectators (all professional dancers) while they watched the videotaped and reduced stick-figure versions of short dance improvisations created in a laboratory installed with motion-capture sensors. Based on the individual narratives, we propose that MA, understood not extensionally (as an empty space or a silent gap), but is intentionally/internally as a certain quality of attention or perceptual mode. This conceptualization of MA is important for the basic research of the interpersonal perception/action as well as for future technologies of nonverbal communications.

(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) This year, we mainly contributed novel mechanisms that expand existing magnetic-based dexterous 3D motion tracking technologies using deep learning and structure-aware filtering techniques. Second, we proposed a spatial virtual reality user interface that offers haptic infrastructure for room-scale virtual environment, where multiple robotic props are dynamically coordinated based on user's motion prediction algorithms.

(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 2020 are summarized as follows: (1) we have proposed a decentralized control mechanism for the body-limb coordination underlying quadruped locomotion; (2) we have proposed a decentralized control scheme for adaptive locomotion of snakes; (3) we have proposed a decentralized control scheme for adaptive one-dimensional crawling locomotion. (4) we have proposed a decentralized control mechanism for biofilm formation through interaction among bacterial cells; (5) we have clarified a community formation process of vampire bats that survive in harsh environments by sharing foods.

(6) Nano-Bio Hybrid Molecular Devices

(Aims) 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.

(Achievements) This year, we developed a solvent-free artificial cell membrane array based on microfabricated Si chips. Parallel recordings of the hERG channel activities in the multiple bilayer lipid membranes were demonstrated, showing the potential of this system as a high-throughput screening for ion-channel proteins. We also constructed a microfluidic device for controlling modular architecture of neuronal networks in dissociated culture. We showed that micropatterned neuronal networks exhibit spontaneous activity with higher functional complexity compared to conventional, unpatterned neuronal networks. Finally, we developed novel sensitive sensors based on organic and nanostructured materials, such as piezoelectric PVDF-based pressure sensors and gas sensors based on TiO2 nanotube film decorated with Pt nanoparticles.

(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 food texture and kinetic sensation of masticatory muscle; the difference of gustatory evoked color-images with auditory evoked color-images; 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.

Electromagnetic Bioinformation Engineering

Communication with human body

Electromagnetic Bioinformation Engineering, Kazushi Ishiyama, Professor
Electromagnetic Biomaterial Engineering, Shuichiro Hashi, Associate Professor

[Research Target and Activities]

To develop a high sensitive microvibration 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. In addition, wireless magnetic motion capture system with four-excitation-coils was studied to improve its detection accuracy. We revealed that (100)[001] silicon steel sheet or (110)[001] silicon steel sheet were useful as magnetostrictive materials for a magnetostrictive power generator to convert vibrational energy into electric energy.

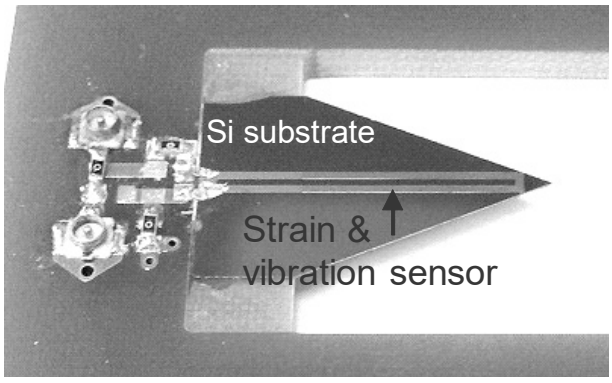

Fig. 1 Strain and vibration sensor using inverse-magnetostrictive effect.

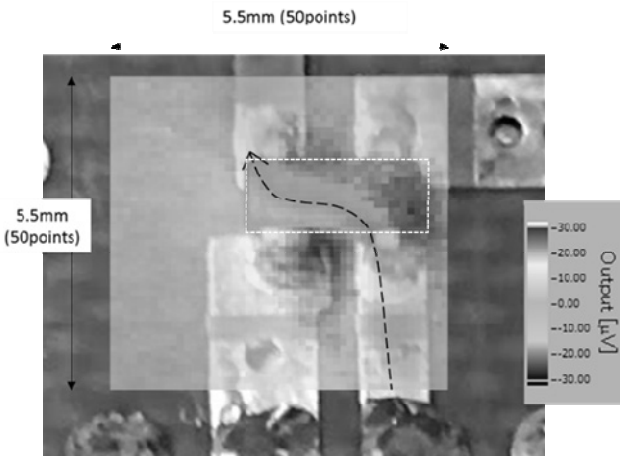

Fig. 2 Image of high frequency magnetic field distribution for internal circuit of voltage controlled oscillator (@623MHz).

[Staff]

Professor: Kazushi Ishiyama, Dr.
Associate Professor: Shuichiro Hashi, 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 in the area of magnetics and magnetic applications.

Shuichiro Hashi received the DE degree in Electrical Engineering from Tohoku University in 1998. His research interests are in the area of magnetic measurement and magnetic materials.

[Papers]

[1] D. Tatsuoka, S. Hashi, and K. Ishiyama, "Proposal of new synchronization method in high frequency near magnetic field measurement using pulsed laser," T. Magn, Soc. Jpn. (Special Issues)., 4, 37-40 (2020).
[2] D. Sora, S. Hashi, and K. Ishiyama, "Evaluating characteristics of strain sensor using inverse-magnetostrictive effect caused by forced vibration," T. Magn, Soc. Jpn. (Special Issues)., 4, 41-45 (2020).
[3] S. Inoue, T. Okada, S. Fujieda, F. Osanai, S. Hashi, K. Ishiyama, S. Seino, T. Nakagawa, T. A. Yamamoto, and S. Suzuki, "High-performance vibration power generation using polycrystalline Fe–Co-based alloy due to large inverse magnetostrictive effect," AIP Advances 11, 035021 (2021).

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.

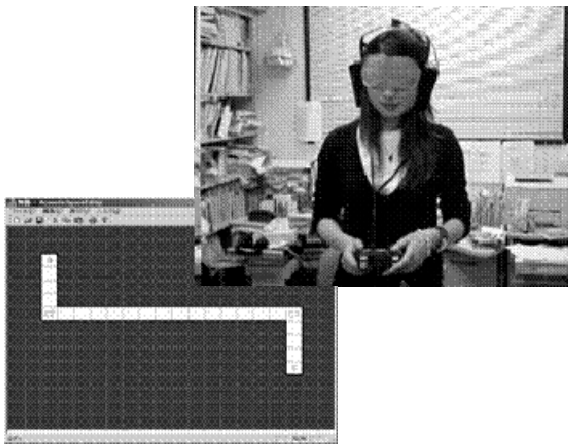

Fig. 1 Application for the training of spatial cognition using a high-definition virtual auditory display

In FY2020, we focused on how humans extract target speech information from distractor sounds by using auditory selective attention. In this year, the effect of auditory selective attention in the spatial domain was analyzed. The auditory spatial attention is one of the important mechanisms to realize cocktail party effects. By directing the attention to the specific direction, humans can extract the target sound easily from spatially distributed distractors. We investigated the effects of listening task on the auditory spatial attention. The results suggest that auditory spatial attention has a strong effect on speech recognition tasks, whereas the auditory spatial attention has a weaker effect on detection tasks of target sound.

[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] R. Teraoka, S. Sakamoto, Z. Cui, Y. Suzuki and S. Shioiri, “Effects of listening task characteristics on auditory spatial attention in multi-source environment,” Acoustical Science and Technology, 42(1), 12-21 (2021).

[2] T. Sato, T. Yabushita, S. Sakamoto, Y. Katori and T. Kawase, “In-home auditory training using audiovisual stimuli on a tablet computer: feasibility and preliminary results,” Auris Nasus Larynx, 47(3), 348-352 (2020).

[3] K. Ozawa, K. Watanabe and S. Sakamoto, "Separation of multiple sound sources in the same direction by instantaneous spectral estimation," Proc. 2020 IEEE 9th Global Conference on Consumer Electronics (GCCE2020), 56-57 (2020).

[4] S. Kim, S.-H. Chon, H. Okumura and S. Sakamoto, "Comparing training effects associated with two sets of HRTF data on auditory localization performance," Proc. AES 148th Convention, 10379 (6 page manuscript) (2020).

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Visual Cognition and Systems Laboratory

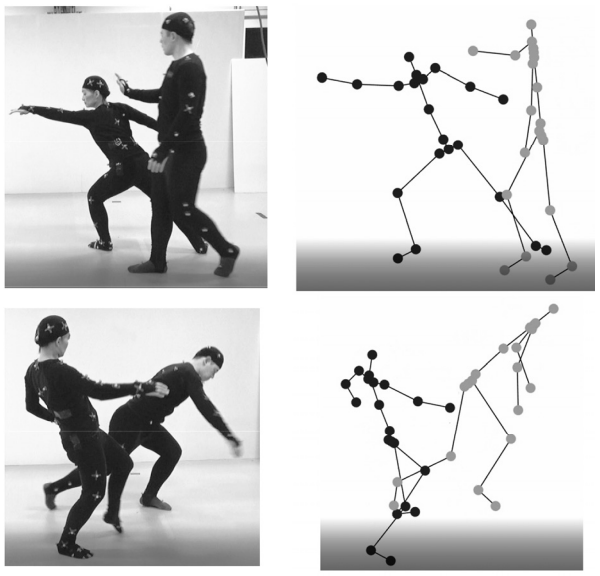
Understanding human visual system for the better communication with visual information

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 investigated the contribution of slow- and fast-motion mechanisms to global motion using motion aftereffect (MAE), and found large contribution of the slow-motion mechanism and little or no contribution of the fast-motion mechanism. These results suggest that the human visual system have multiple motion processes specialized for different stimulus conditions. Secondly, we interviewed performers and spectators (all professional dancers) while they watched the videotaped and reduced stick-figure versions of short dance improvisations created in a laboratory installed with motion-capture sensors. Based on the individual narratives, we propose that MA, understood not extensionally (as an empty space or a silent gap), but is intentionally/internally as a certain quality of attention or perceptual mode. This conceptualizaation of MA is important for the basic research of the interpersonal perception/action as well as for future technologies of nonverbal communications.



Visual stimuli used for judgments of ittaikan and MA. Two dancers in joint improvisation.

[Staff]

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

[Profile]

Satoshi SHIOIRI Professor Shioiri graduated from 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.
Ichiro KURIKI Dr. Kuriki received Ph.D. degree from Tokyo Institute of Technology in 1996. After that, he worked at Imaging Science and Engineering Laboratory, Tokyo Institute of Technology as a research associate until October, 1999. He worked as a research associate at the Department of Mathematical Engineering and Information Physics, Graduate School of Engineering, the University of Tokyo until March, 2001. He worked as a researcher in Communication Science Laboratories of NTT Corporation until December, 2005. He joined the Research Institute of Electrical Communication, Tohoku University as an Associate Professor in January, 2006.
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.

Information Content

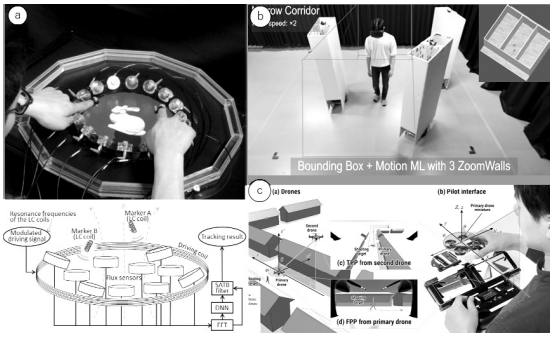
Technologies for Interactive Content

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 two topics; first, we proposed a new dexterous 3D motion tracking system using deep learning and structure-aware flirting [1]. Second, we proposed a novel encounter-type haptic device for room-scale VR applications using coordinated multiple autonomous robotic wall-shaped props [2].



[Staff]

Professor: Yoshifumi Kitamura, Dr.
Associate Professor: Kazuki Takashima, Dr.
Assistant Professor: Kazuyuki Fujita, Dr.
Assistant Professor: Kaori Ikematsu, 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] Jiawei Huang, Ryo Sugawara, Kinfung Chu, Taku Komura, Yoshifumi Kitamura, Reconstruction of Dexterous 3D Motion Data from a Flexible Magnetic Sensor with Deep Learning and Structure-Aware Filtering, *IEEE Transaction on Visualization and Computer Graphics* (Early Access), 2020.

[2] Yan Yixian, Kazuki Takashima, Anthony Tang, Takayuki Tanno, Kazuyuki Fujita, Yoshifumi Kitamura. ZoomWalls: Dynamic Walls that Simulate Haptic Infrastructure for Room-scale VR Worlds, *In Proceedings of User Interface Software and Technology (UIST '20)*, 223-235, 2020

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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.

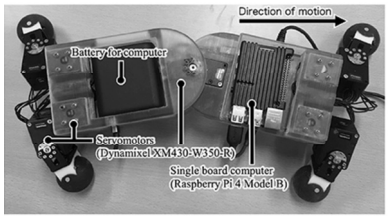


Fig.1: Legged robot that can coordinate body and limb motions like sprawling quadrupeds

Fig.2: Snake-like robot that can generate adaptive 3D locomotion patterns

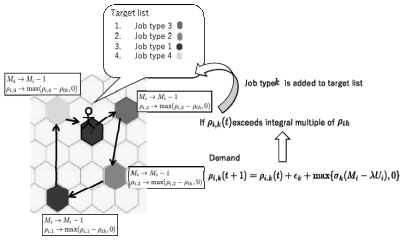


Fig.3: Agent-based model of the interrelation between COVID-19 outbreak and economic activities

[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] S. Suzuki, T. Kano, A. J. Ijspeert, A. Ishiguro, "Sprawling Quadruped Robot Driven by Decentralized Control With Cross-Coupled Sensory Feedback Between Legs and Trunk", Frontiers in Neurorobotics, 14, 607455
[2] T. Kano, A. Ishiguro, "Decoding Decentralized Control Mechanism Underlying Adaptive and Versatile Locomotion of Snakes", Integrative and Comparative Biology, 60, 1, 232-247
[3] T. Kano, K. Yasui, T. Mikami, M. Asally, A. Ishiguro, "An agent-based model of the interrelation between the COVID-19 outbreak and economic activities", Proceedings of the Royal Society A, 477, 20200604

Nano-Bio Hybrid Molecular Devices

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

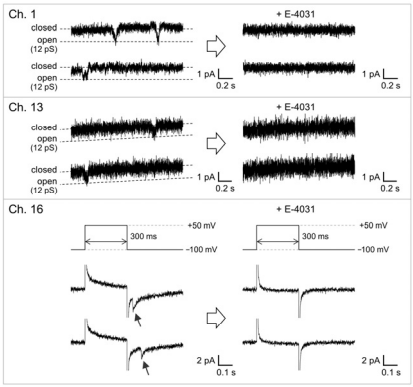
Nano-Bio Hybrid Molecular Devices: Ayumi Hirano-Iwata, Professor

[Research Target and Activities]

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

1. Parallel recordings of hERG channel currents based on solvent-free artificial cell membrane array

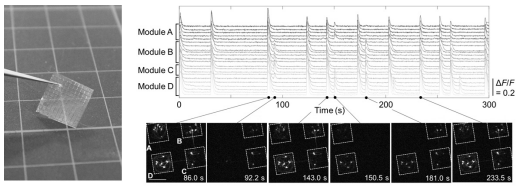
We developed a solvent-free artificial cell membrane array based on microfabricated Si chips. Parallel recordings of the hERG channel activities in the multiple bilayer lipid membranes (BLMs) were demonstrated, showing the potential of the present BLM system as a high-throughput screening platform for ion-channel proteins. [Micromachines, **12**, 98 (2021); Chem. Lett., **50**, 418–425 (2021).]



Parallel recordings of hERG channel activities.

2. Microfluidic device for patterning neuronal networks

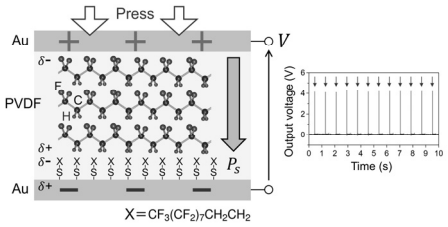
We developed a microfluidic device for controlling modular architecture of living neuronal networks in dissociated culture. We showed that micropatterned neuronal networks exhibit spontaneous activity with higher functional complexity compared to conventional, unpatterned neuronal networks. [Jpn. J. Appl. Phys., **59,** 117001 (2020).]



Microfluidic device for patterning neuronal networks.

3. Piezoelectric PVDF-based pressure sensors / Highly sensitive gas sensors using a TiO_2 nanotube film

We developed piezoelectric PVDF-based pressure sensors fabricated by using a novel poling method. We also proposed highly sensitive gas sensors using a TiO_2 nanotube film decorated with Pt nanoparticles as catalysts. [Sens. Act. A, **316**, 112424 (2020); Sens. Act. B, **321**, 128525 (2020).]



Piezoelectric PVDF-based pressure sensor.

[Staff]

Professor: Ayumi Hirano-Iwata, Dr.

[Profile]

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

[Papers]

[1] R. Miyata, D. Tadaki, D. Yamaura, S. Araki, M. Sato, M. Komiya, T. Ma, H. Yamamoto, M. Niwano, A. Hirano-Iwata, "Parallel recordings of transmembrane hERG channel currents based on solvent-free lipid bilayer microarray", Micromachines, **12**, 98 (2021).

[2] T. Takemuro, H. Yamamoto, S. Sato, A. Hirano-Iwata, "Polydimethylsiloxane microfluidic films for in vitro engineering of small-scale neuronal networks", Jpn. J. Appl. Phys., **59**, 117001 (2020).

[3] D. Tadaki, T. Ma, S. Yamamiya, S. Matsumoto, Y. Imai, A. Hirano-Iwata, M. Niwano, "Piezoelectric PVDF-based sensors with high pressure sensitivity induced by chemical modification of electrode surfaces", Sens. Act. A, **316**, 112424 (2020).

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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. 2020 to Mar. 2021 of these fields except the visitor section is described in this section.

(1) Software Construction

We research on theoretical foundations for flexible and reliable programming languages. We also develop SML#, a new programming language in the ML family that embodies our foundational research results. The major results of the 2020 academic year include the following. On theoretical foundations, we have considered nominal rewriting with atom variables, and have developed a new confluence criterion and a sufficient condition for commutation, which generalizes confluence criteria. On practical implementation methodology, we have extended the last year's result and have established a parallel and concurrent garbage collection method for lightweight threads, where parallel collection is performed fully concurrently with millions of light-weight threads. Our benchmark evaluation showed that this GC-powered SML# out-performs most of existing parallel and concurrent languages. This GC has been integrated in SML# version 4.0.0 and released to the world functional language community.

(2) Computing Information Theory

We studied formal language theory as a theoretical basis for software verification and research on bi-directional transformation which is applied to data synchronization and data sharing. One of our research results is a relationship between classes of tree transducers. Tree transducers, which are transformation models on tree-structured data in formal language theory, are classified into many classes according to their descriptions, and these classes are roughly classified into two types by representation of trees, tree transformation style and stream processing style. In our research in FY2020, we succeeded in proving the identity of expressive power between two classes of the different styles. As a result, we found the decidability of equivalence of a particular transformation class in a stream processing style, which has not been known in previous work. We also developed a computational model for involutions which can be a basis of bidirectional transformation theory. This model, which

is a syntactically-restricted Turing machine, covers all possible involutions and has been proved to be universal. The model of computation can also be applied to the characterization of bidirectional programming languages.

(3) Communication Network Systems

We promoted the following research on information networking technologies that support various human activities and its application. In the area of mobile core network architecture, we proposed the control-plane signaling method for controlling the demand on the server resources for accommodating massive M2M/IoT devices, gave mathematical analysis for function splitting in 5G networks, and presented performance evaluation methods of mobile cellular networks considering the interactions between wireless access networks and core networks. For new network architecture for beyond 5G, we proposed a new network slicing architecture, that is based on fine and heterogeneous resolution of network slicing and introducing sub-slice provider and network slice broker for efficient and scale-free network slice construction. Furthermore, in the research on agent-based IoT and its applications, we proposed a dedicated ontology for the flexible coordination of IoT devices, proposed IoT service composition method utilizing the ontology, and provided a design of the data-saving mobile agent framework for IoT devices. We also conducted a fundamental study to merge replicas of isolative operated services without inconsistency.

(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, as security computing technology for IoT devices, we developed a hardware architecture that unifies typical encryption modes based on the international standard cryptography AES (Advanced Encryption Standard) with the world's highest efficiency in addition to designing the world’s highest efficient AES hardware. We also found a new implementation vulnerability on low-latency cryptographic system and developed its countermeasure technology. The validity of the countermeasure was demonstrated by an experiment with an actual device. Furthermore, we developed a method to significantly improve the stability and efficiency of information communication systems based on physically unclonable functions extracted from hardware, which are applied to individual identification and secret key generation, and showed its effectiveness from both theories and experiments.

(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 analyzed the high-dimensional complex dynamics of the chaotic neural network reservoir through information theoretic and dynamical theoretic measures. We also investigated the effects of the exponentially decaying internal state of the neuron on the performance in chaotic time-series prediction and speech recognition tasks. In

addition, we implemented a prototype chip for a TSV 3D stacked cyclic chaotic neural network reservoir LSI. Through the experiments, we confirmed the functionality of the chip. (ii) We proposed mathematical and circuit models for neuron-like and synapse-like spintronics devices based on the device temperature dynamics. (iii) We proposed an efficient method to implement small and high-speed cryptographic hardware based on the augmented Lorenz-map, and validated it using FPGA experiments. A key exchange method based on the chaos synchronization was also proposed.

(6) New Paradigm VLSI System

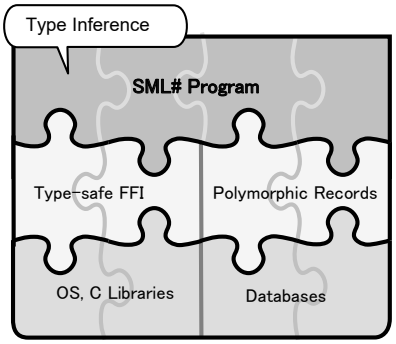
Our research activity is to solve the several limitations such as power dissipation, performance and reliability due to the present binary-CMOS-based VLSI computing. The key approach to breaking through such limitations is primarily the following two ways: the logic-in-memory architecture based on nonvolatile 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 in realizing energy-efficient learning hardware based on CMOS invertible logic (CIL). We applied CIL, which makes it possible to realize "bidirectional calculation" on a CMOS integrated circuit, which is difficult to realize with conventional CMOS-logic-based computing, to neural network learning. By utilizing bidirectional computation, we have devised a hardware-friendly learning algorithm that does not use the error back-propagation method, which is a conventional learning algorithm that requires floating-point arithmetic, and trains in FPGA and ASIC for small-scale neural networks. As a result, compared with the conventional method, energy reduction of 3 digits or more was achieved while maintaining the same learning accuracy. The results of this year's research, including the above, are 10 academic journal papers, 6 peer-reviewed international conference papers, and 5 invited lectures (including 1 international conference), which includes IEEE Symposium on VLSI Circuits, one of the highest international conferences on cutting-edge integrated circuit technology, and IEEE TCAS-I, one of the highest academic journals in the field of circuits and systems.

Software Construction Laboratory

Foundations for Developing High-level and Reliable Programming Languages

Software Construction Atsushi Ohori, Professor
Reliable Software Development Katsuhiro Ueno, Associate Professor

[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.

The major results of the 2020 academic year include the following. On theoretical foundations, we have studied nominal rewriting with atom variables, and have developed a new confluence criterion and a sufficient condition for commutation [1]. On practical implementation methodology, we have established a parallel and concurrent garbage collection method, where parallel collection is performed fully concurrently with millions of light-weight threads. Our benchmark evaluation showed that SML# equipped with this GC outperforms most of existing parallel and concurrent languages [2]. This GC has been integrated in SML# version 4.0.0 and released to the world functional langauge community.

[Staff]

Professor : Atsushi Ohori, Ph.D.
Associate Professor : Katsuhiro Ueno, Dr.
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, he has been an associate professor at the same institute.

[Papers (conference presentations)]

[1] Kentaro Kikuchi, Takahito Aoto: Confluence and Commutation for Nominal Rewriting Systems with Atom-Variables. In Proceedings of the International Symposium on Logic-based Program Synthesis and Transformation (LOPSTR'20), LNCS 12561, pp. 56-73, 2021, DOI: 10.1007/978-3-030-68446-4_3.
[2] Katsuhiro Ueno, Atsushi Ohori: Parallel constructs of SML# and their performance (in Japanese), Proceedings of the 37th annual meeting of Japan Society for Software Science and Technology, 5 pages、September, 2020.

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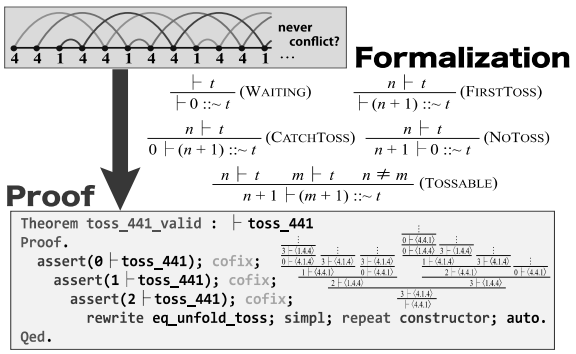
Computing Information Theory

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] Yuta Takahashi, Kazuyuki Asada, and Keisuke Nakano, "Streaming Ranked-Tree-to-String Transducers", Theoretical Computer Science, Volume 870, Jan 2021 (online first), Pages 165-187.
[2] Keisuke Nakano, "Involutory Turing Machines", Proc. 12th International Conference on Reversible Computation (RC 2020), Oslo (online), LNCS 12227, 2020, pp. 54-70.
[3] Kazuyuki Asada and Naoki Kobayashi, “Size-Preserving Translations from Order-(n+1) Word Grammars to Order-n Tree Grammars”, Proc. 5th International Conference on Formal Structures for Computation and Deduction (FSCD 2020), Paris (online), LIPIcs 167, 2020, pp. 22:1--22:22.

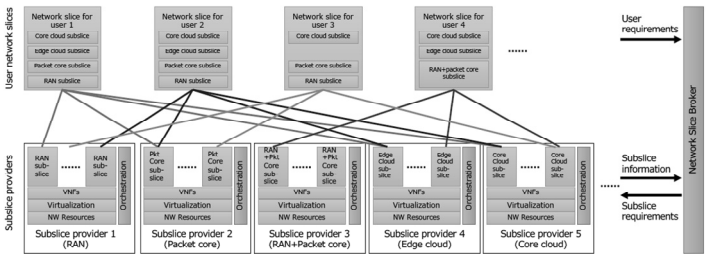
Communication Network Systems

Information Network Architecture for the IoT Society

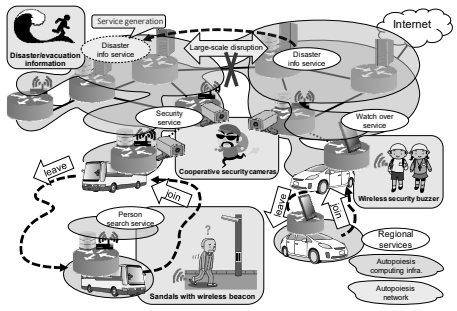
Information Network Architecture: Go Hasegawa, Professor
Intelligent Network: Gen Kitagata, Associate Professor

[Research Target and Activities]

In this year, the following studies had been done. (a) Researches on mobile network architecture to efficiently accommodate a large number of Machine-to-Machie (M2M) and Internet of Things (IoT) terminals. (b) Research on new network architecture for future beyond-5G networks, that is based on fine and heterogeneous resolution of network slicing and introducing sub-slice provider and network slice broker for efficient and scale-free network slice construction. (c) Research and development of basic technologies for autopoietic computing platforms that allow various IoT devices, including mobile devices, to autonomously configure computing platforms for the next generation of IoT themselves.



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] Go Hasegawa, Masayuki Murata, Yoshihiro Nakahira, Masayuki Kashima, and Shingo Ata, “Optimizing functional split of baseband processing on TWDM-PON based fronthaul network,” in Proceedings of The 16th International Conference on Mobility, Sensing and Networking (IEEE MSN 2020), December 2020.

[2] Shuya Abe, Go Hasegawa, and Masayuki Murata, “Performance analysis of periodic cellular-IoT communication with immediate release of radio resources,” in Proceedings of IEEE CQR 2020, May 2020. (Best Paper Award)

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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 developed energy-efficient cryptographic hardware for AES, which is the most commonly used cipher in the world. Then, we have also developed cryptographic hardware which efficiently executes cipher modes of operations for, for example, memory protection and Internet communication. In addition, we have discovered practical attacks on cryptographic implementations of low-latency cipher and message authentication codes with experimental validation (Fig. 1) and developed its countermeasure. Furthermore, we have developed secure and efficient hardware authentication systems based on hardware-intrinsic ID from physically unclonable function (PUF).

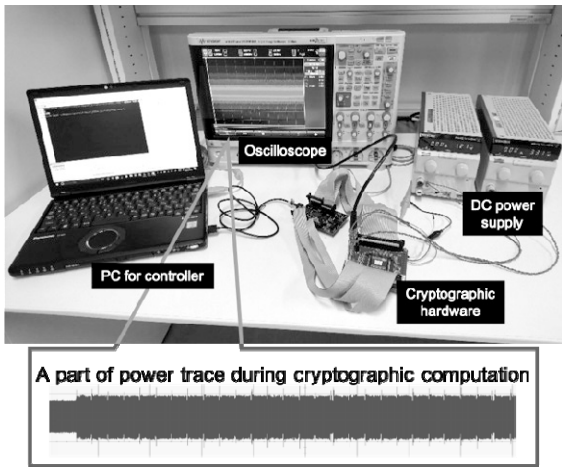


Fig. 1: Experiment for security evaluation of cryptographic hardware

[Staff]

Professor: Naofumi Homma, Ph. D
Assistant Professor: Rei Ueno, Ph. D
Specially Appointed Assistant Professor: Ville Yli-Mäyry, 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] R. Ueno *et al*., "Highly Efficient AES Hardware Architectures Based on Datapath Compression," *IEEE Transactions on Computers*, Vol. 69, Issue 4, pp. 534—548, 2020.
[2] M. Oda *et al*., "PMAC++: Incremental MAC Scheme Adaptable to Lightweight Block Ciphers," In *IEEE International Symposium on Circuit and Systems*, 2020.
[3] S. Sawataishi *et al*., "Unified Hardware for High-Throughput AES-Based Authenticated Encryptions," *IEEE Transactions on Circuits and Systems I: Regular papers*, Vol. 67, Issue 9, pp. 1604—1608, 2020.
[4] Ville Yli-Mäyry *et al*., "Diffusional Side-channel Leakage from Unrolled Lightweight Block Ciphers: A Case Study of Power Analysis on PRINCE," *IEEE Transactions on Forensics & Security*, 2020.
[5] Rei Ueno *et al*., "Single-Trace Side-Channel Analysis on Polynomial-based MAC Schemes," In *International Workshop on Constructive Side-channel Analysis and Secure Design*, springer, 2020.
[6] R. Ueno *et al*., "A method for constructing sliding windows leak from noisy cache timing information," Journal of Cryptographic Engineering," *Journal of Cryptographic Engineering*, 2020.
[7] Rei Ueno *et al*., "Rejection Sampling Schemes for Extracting Uniform Distribution from Biased PUFs," IACR Transactions on Cryptographic Hardware and Embedded Systems, Vol. 2020, Issue 4, pp. 86—128, 2020.
[8] K. Kazumori *et al*., "Debiasing Method for Efficient Ternary Fuzzy Extractors and Ternary Physically Unclonable Functions," *IEEE 50th International Symposium on Multiple-Valued Logic*, 2020.

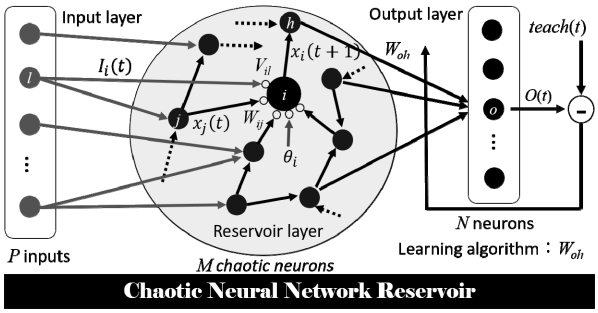
Soft Computing Integrated System

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 2020; 1) We analyzed the dynamics of the chaotic neural network reservoir (CNNR) using measures for information theory and nonlinear dynamics measures. We integrated a prototype IC chip for TSV 3D stacked integration of the CNNR; 2) We proposed compact mathematical models for neuron-like and synapse-like spintronics devices based on the device temperature dynamics; and 3) We proposed an efficient method to implement small and high-speed cryptographic hardware based on the augmented Lorenz-map, and a key exchange method based on chaos synchronization.



[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] T. Orima and Y. Horio, "A design method for a passive reflectionless transmission-line model based on the cochlea through parameter optimization techniques," Nonlinear Theory and Its Applications, IEICE, vol. 11, no. 4, pp. 624-635, DOI: 10.1587/nolta.11.624, October 1, 2020.

[2] K. Miyauchi, Y. Horio, T. Miyano, K. Cho, "Design of the nonlinear look-up table in the chaotic pseudorandom number generator based on augmented Lorenz map," Nonlinear Theory and Its Applications, IEICE, vol. 11, no. 4, pp. 571-579, DOI: 10.1587/nolta.11.571, October 1, 2020.

[3] A. Shinozaki, T. Miyano, and Y. Horio, "Chaotic time series prediction by noisy echo state network," Nonlinear Theory and Its Applications, IEICE, vol. 11, no. 4, pp. 466-479, DOI: 10.1587/nolta.11.466, October 1, 2020.

New Paradigm VLSI System Research Group

Realization of a New-Paradigm VLSI-Computing World

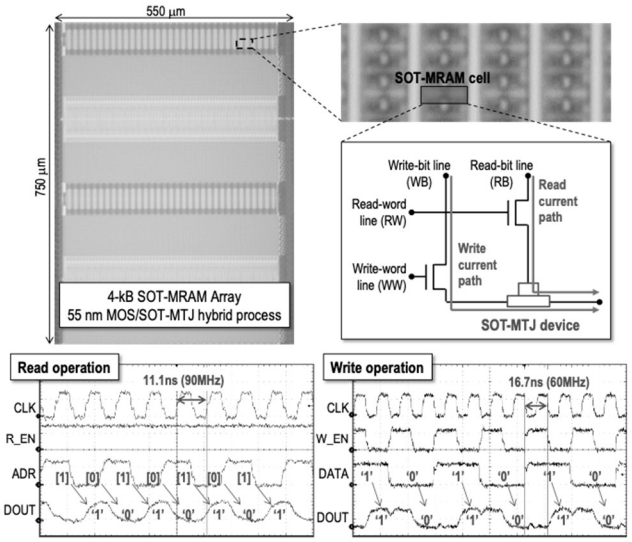


Fig. 1. A dual-port nonvolatile memory using 3-terminal spintronics devices (SOT-MRAM) achieving high-speed read / write / read-during-write operations

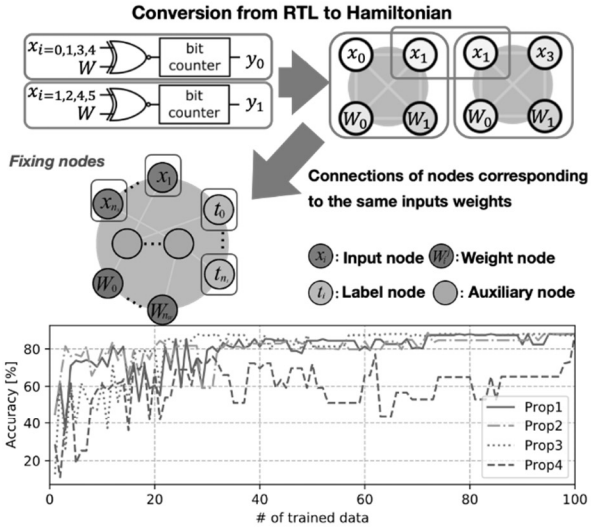


Fig. 2. Training hardware based on CMOS invertible logic achieves 40x faster and 1/130x smaller power dissipation than a conventional training algorithm

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 stochastic-computing based CMOS invertible logic that realizes bidirectional computing for training neural networks (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.

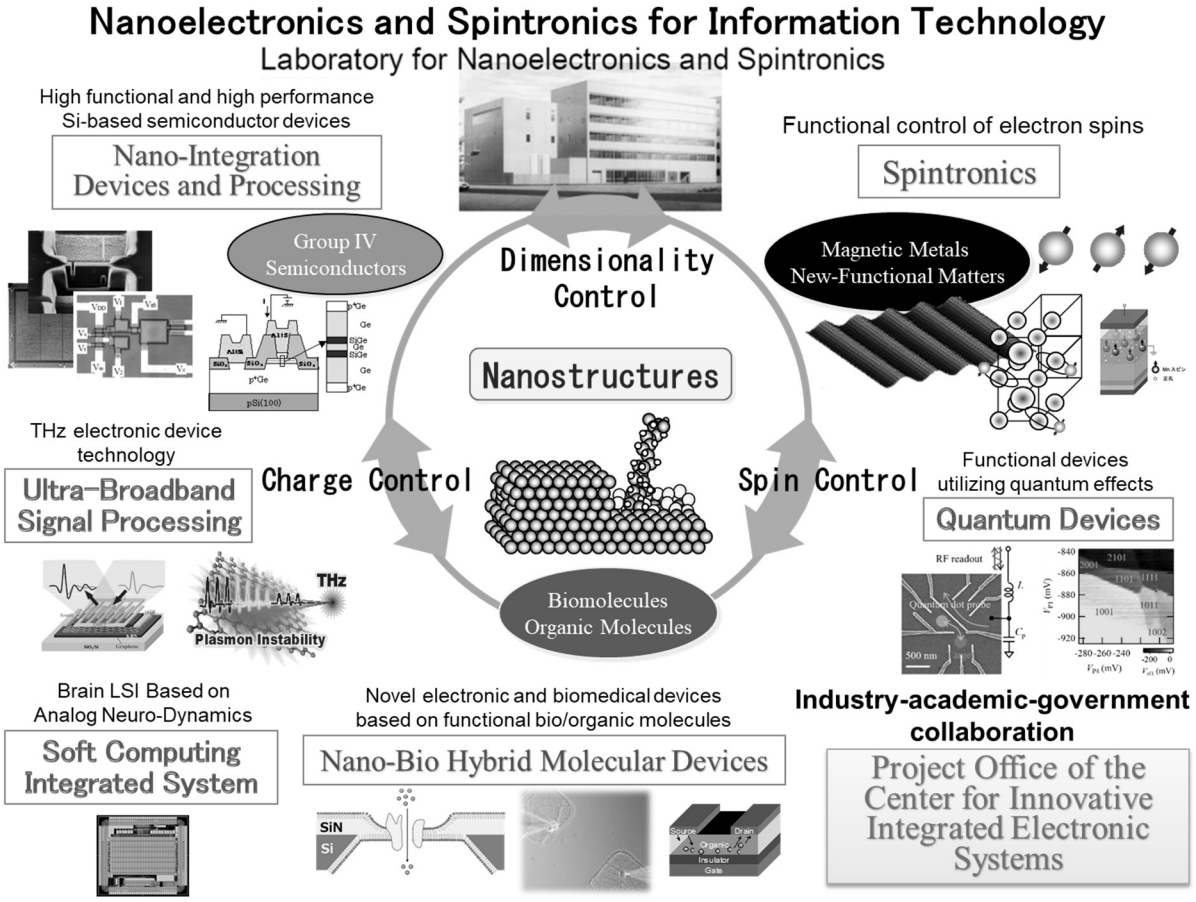
Masanori Natsui received the Ph.D. degrees in information Sciences from Tohoku University, Sendai, Japan, in 2005. His research interest includes automated circuit design technique, nonvolatile-based circuit architecture and its application, and design of high speed low-power integrated circuits.

[Papers]

[1] M. Natsui, et al., 2020 Symp. VLSI Circuits, 2 pages, June 2020.
[2] D. Shin, et al., IEEE Access, vol.8, pp.188004-188014, Oct. 2020.
[3] R. Arakawa, et al., IEEE Trans. Circuits and Systems I, vol.68, no. 1, pp.67-76, Jan. 2021.
[4] N. Onizawa, et al., IEEE Trans. Circuits and Systems I, vol. 67, no. 5, pp.1541-1550, May 2020.

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 2020 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 developed a spiking neuron circuit that can reproduce various neuron pulses with ultra-low power consumption. We confirmed by numerical simulations that the power consumption of our analog MOS circuit is less than 10 nW when it operates in the weak inversion region.
(2) Toward the realization of Si crystal structure transformation into penta-silicene, we performed selective etching of Ge in a Ge/ultrathin Si/Ge heterostructure in which a 5 nm-thick Si film was sandwiched by Ge. We confirmed that micrometer-scale isolated Si films were obtained, which indicates that a crosslinked structure of Si can be formed by this method.
(3) In the fabrication of SiC Schottky barrier diode, influence of Al electrode deposition method was investigated. We confirmed that, while the electron-beam evaporation method showed a possibility of degradation in crystallinity and interface properties, the RF sputtering method enabled superior diode fabrication with significant suppression of reverse bias current.
(4) We designed an analog circuit that recapitulates the function of spike-timing dependent plasticity, a biologically plausible learning rule for artificial neural networks. The number of transistors in a circuit was reduced by 20% for future implementation in ultralow-power edge computing devices.
(5) Modular architecture is a network structure that evolutionarily conserved in animals' nervous system, and Hough transformation is a model consistent with the mechanisms of information processing in the visual cortex. We used computational simulation to show that the two biologically plausible mechanisms help improve the computational efficiency and robustness against system damage in a reservoir computing model for image recognition.

● Soft Computing Integrated System (Y. Horio)

(1) We analyzed the dynamics of the chaotic neural network reservoir (CNNR) usin
g combinations of the measures for information theory and nonlinear dynamics such as Lyapunov spectrum, permutation entropy, spatial mutual information, average firing rate, and Kullback-Leibler divergence. We also introduced complexity-entropy causality plane. We found that the exponentially decaying internal state of the neuron greatly affect the performance of speech recognition and nonlinear time-series prediction tasks. We integrated a prototype IC chip for TSV 3D stacked integration of the CNNR; and confirmed the functionality of the prototype chip through experiments.
(2) We implemented compact mathematical models for neuron-like and synapse-like spintronics devices based on the temperature dynamics. We then tuned the model parameters using experimental data.
(3) We implemented small and high-speed cryptographic hardware based on the augmented Lorenz-map using FPGA. In addition, we investigated a key-exchange method based on chaos synchronization. Furthermore, we prepared for a long-distance communication experiment using the proposed chaotic encryption system.

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) Succeeding in fabricating three-dimensional self-assembly nanostructure made of magnetic material and elucidating the magnetic structure by means of electron holography, (2) putting forward an analytical and numerical scheme to derive the current distribution of metallic multilayer based on Boltzmann transport theory, (3) investigating the spin-orbit torque generation efficiency in heterostructures with antiferromagnetic PtMn and ferromagnetic CoFeB, and obtaining a new insight of the spin-orbit torque generated by antiferromagnets, (4) succeeding in electric field modulation of the properties of spin Hall nano oscillator, that is promising as an artificial synapse, (5)

successfully demonstrating the current-driven manipulation of Neel vector of polycrystalline PtMn which has a compatibility with semiconductor processes, (6) revealing the mechanism of all optical switching in ferrimagnet/non-magneto/ferromagnet heterostructure, and demonstrating a new energy efficient scheme of all optical switching, (7) developing the world-smallest magnetic tunnel junction down to 2.3 nm with high performance using ferromagnetic multilayer structure and shape anisotropy, (8) developing a new magnetic tunnel junction device operated with both spin-transfer torque and spin-orbit torque and achieving the world fastest magnetization switching of the pulse width of 200 ps, (9) establishing a new theoretical framework to describe the stochastic behavior of superparamagnetic nanomagnet and achieving the world fastest random telegraph noise of 8 ns.

● **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 2020FSY.

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 photonics-electronics convergence mixers

To realize the carrier frequency down-conversion from optical to wireless data signals, which is one of key technologies in future photonics-electronics convergence networks, we developed a novel device that introduces a photoabsorption structure of a unitraveling-carrier photodiode into an InGaAs-channel high-electron-mobility transistor and successfully demonstrated the gain enhancement of the frequency down-conversion from 1.5-μm optical data signal to millimeter-wave data signal by one order of magnitude by reducing the active area size of the photodiode.

● **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 2020 are the following.

(1) We developed the local electronic sensors which can directly access local electronic states in nanostructures utilizing semiconductor quantum dots. We improved the performance by high-frequency measurement techniques and data informatics approaches.

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

(3) We studied semiconductor quantum bits for future quantum information processing. We conducted experiments on quantum bit operations 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 solvent-free artificial cell membrane array based on microfabricated Si chips. Parallel recordings of the hERG channel activities in the multiple bilayer lipid membranes (BLMs) were demonstrated, showing the potential of the present BLM system as a high-throughput screening platform for ion-channel proteins.

(2) We developed a microfluidic device for controlling modular architecture of living neuronal networks in dissociated culture. We showed that micropatterned neuronal networks exhibit spontaneous activity with higher functional complexity compared to conventional, unpatterned neuronal networks.

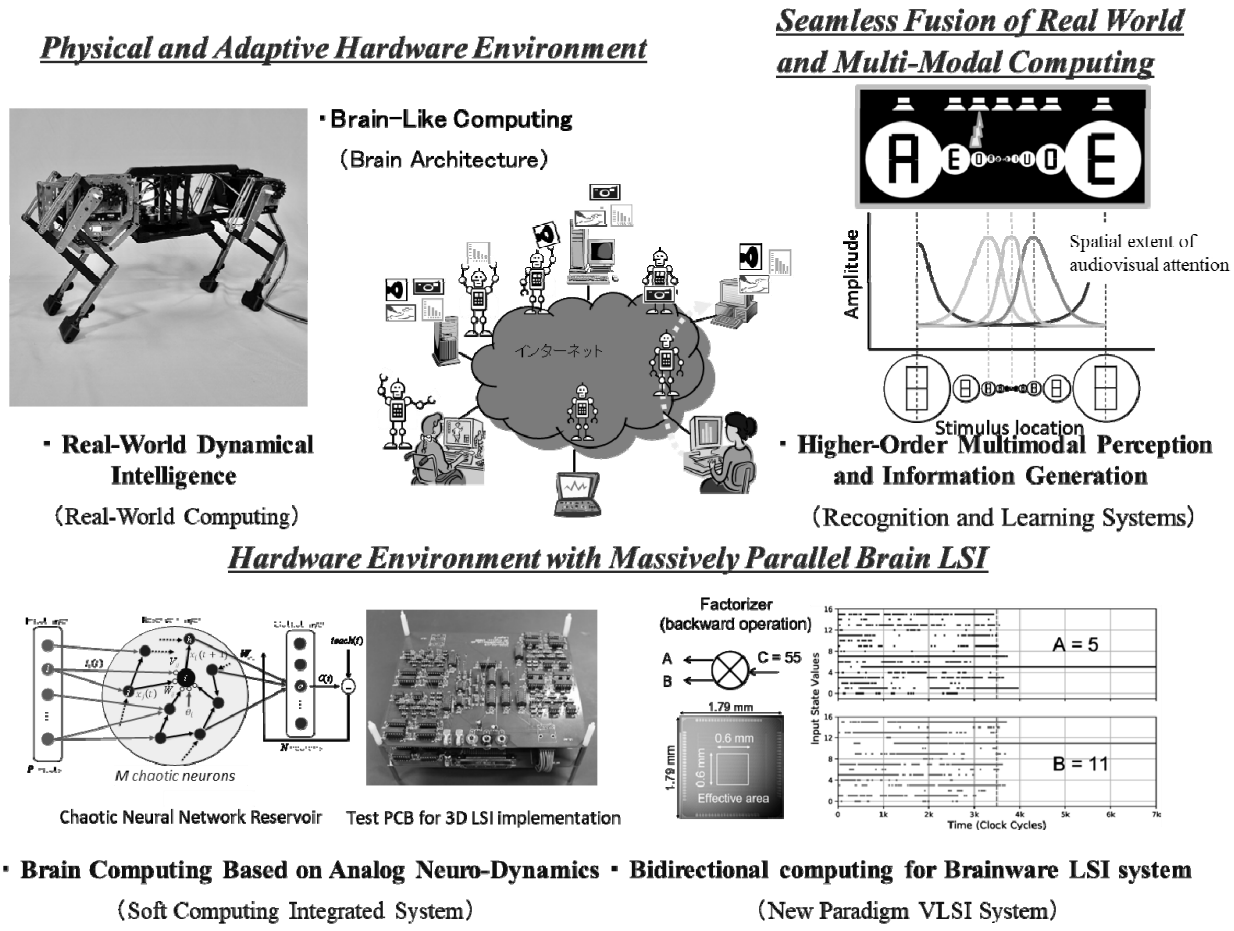
(3) We developed piezoelectric PVDF-based pressure sensors fabricated by using a novel poling method. We also proposed highly sensitive gas sensors using a TiO2 nanotube film decorated with Pt nanoparticles as catalysts.

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

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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 2020 are an important step towards the goal as:

--Real-World Computing Section demonstrates "Sprawling Quadruped Robot Driven by Decentralized Control with Cross-coupled Sensory Feedback between Legs and Trunk" reported in Frontiers in Neurorobotics.
https://www.frontiersin.org/articles/10.3389/fnbot.2020.607455/full

--New Paradigm VLSI System Section has succeeded in demonstrating the operation of a dual-port SOT-MRAM cell array that can read and write at the same time.
https://www.nikkei.com/article/DGXLRSP535812_V10C20A6000000/
https://eetimes.jp/ee/articles/2006/18/news027.html

--Recognition and Learning Systems Section demonstrates "Effects of listening task characteristics on auditory spatial attention in multi-source environment" reported in Acoustical Science and Technology.
https://www.jstage.jst.go.jp/article/ast/42/1/42_E2002/_article/-char/ja/

--Soft Computing Integrated System Section develops "Cyclic reservoir neural network circuit for 3D IC implementation" reported in Nonlinear Theory and Its Applications, IEICE.
https://www.ieice.org/publications/nolta/

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 the role of the slow motion detection process for global motion identification. Analyzing global motion is one of important visual functions to understand the world and also self. Motion of an object provides shape information of the object and motion of whole visual field provide information of self-motion. The present study revealed an important role of slow motion signal for global motion perception. Since we often see slowly moving object and visual motion through slow self-motion, the use of slow-motion signals to global motion analysis is physiologically plausible.

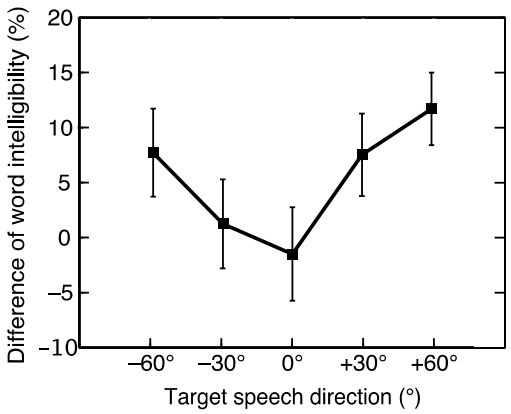


Figure. Directional dependency of auditory spatial attention in the horizontal plane. The listener directs his/her auditory selective attention to the frontal direction (0 degree). When the target speech sound is presented from the direction under noisy environments, the listener easily extracts the target speech sound.

Second, we investigated how humans extract target speech information from distractor sounds by using auditory selective attention. We especially analyzed the effect of auditory selective attention in the spatial domain. The auditory spatial attention is one of the important mechanisms to realize cocktail party effects. We measured the shape of the spatial window of auditory spatial attention and revealed that there is no directional dependency in the effect of auditory spatial attention. This tendency was observed not only in front of the listener but also behind the listener. Moreover, the spatial pattern of the auditory selective attention was different for the listening tasks.

[Staff]

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

[Papers]

[1] S. Shioiri, K. Matsumiya, and C. H. Tseng, “Contribution of the slow motion mechanism to global motion revealed by an MAE technique,” *Scientific Reports,* vol. 11, no. 1, pp. 3995, 2021.

[2] T.J.T. Hsieh, I. Kuriki, I.P. Chen, Y. Muto, R. Tokunaga, S. Shioiri, "Basic color categories in Mandarin Chinese revealed by cluster analysis," *Journal of Vision*, 20 (12), 6-6, 2020

[3] R. Teraoka, S. Sakamoto, Z. Cui, Y. Suzuki, & S. Shioiri, "Effect of auditory spatial attention in rear side," *Proc. 179th Meeting of the Acoustical Society of America*, 3aPP8, 2619-2619, 2020.

[4] R. Teraoka, S. Sakamoto, Z. Cui, Y. Suzuki, & S. Shioiri, "Effects of listening task characteristics on auditory spatial attention in multi-source environment," *Acoustical Science and Technology*, 42(1), 12-21, 2021.

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 Technologies to Densely and Efficiently Utilize Radio Resources of Unlicensed Bands

From 2017, the mobile wireless technology group has started a 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. In this project, we are going to develop a real-time frequency monitor to avoid the interference between different wireless systems in dedicated areas such as factory or office. This year, we have developed a prototype of miniaturized 0.8 to 6GHz-band/real-time spectrum monitor which can detect ms order burst signal/noise. After field test, we have closed this R&D project successfully.

・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 new 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 are going to develop a 5GHz-band simplified beam forming wireless IoT communication system using Wi-Fi backscatter.

[Staff]

Director: Noriharu Suematsu, Professor

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

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

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

Dependable Air

Noriharu Suematsu, Professor (Project Leader)
Suguru Kameda, Associate Professor
Mizuki Motoyoshi, Assistant Professor
Takashi Shiba, Specially Appointed Professor

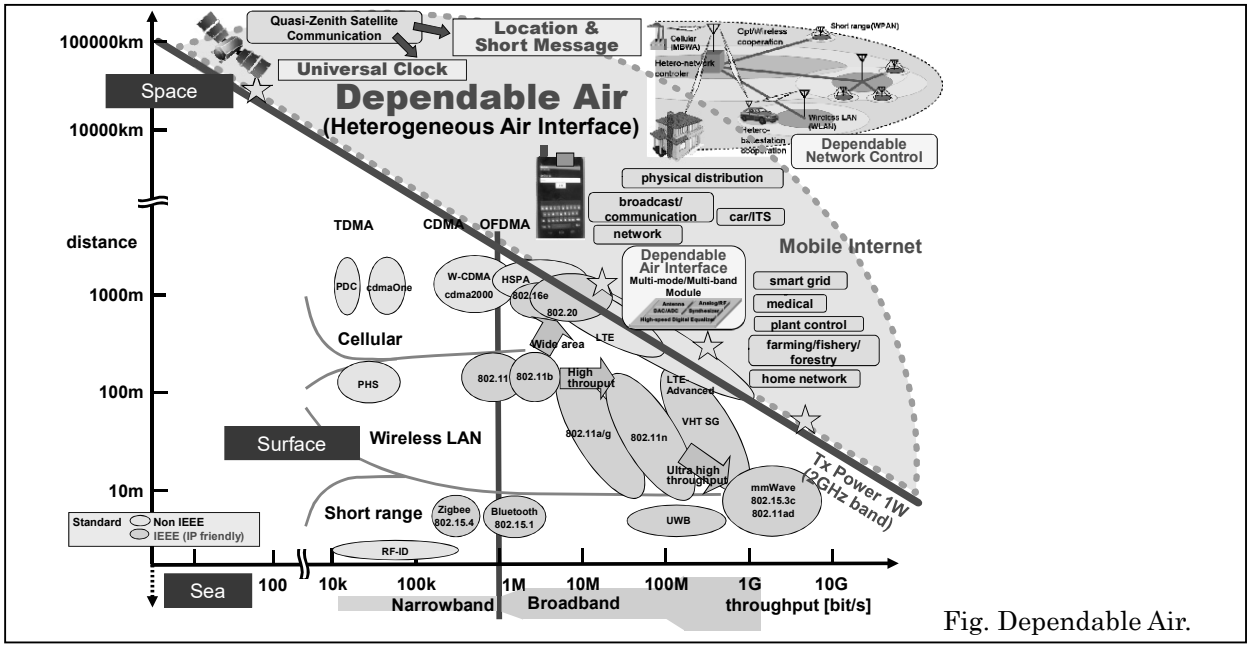


Fig. Dependable Air.

[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. The group has started 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 from 2017. The group has also started a new R&D 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 from 2019.

[Staff]

Professor: Noriharu Suematsu, Ph.D
Associate Professor: Suguru Kameda, Ph.D
Assistant Professor: Mizuki Motoyoshi, Ph.D
Specially Appointed Professor: Takashi Shiba, Ph.D

[Papers]

[1] T. Machii, K. Edamatsu, M. Motoyoshi, S. Kameda, N. Suematsu, "Link Design and Received Power Measurement of 5 GHz Band Wi-Fi Backscatter System Using a Miniaturized Antenna Module," 2020 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), pp. 226-228, Sep. 2020.

[2] K. Edamatsu, T. Machii, M. Motoyoshi, S. Kameda, N. Suematsu, "5-GHz Band Wi-Fi Backscatter System for Multiple Sensor Nodes Identification," 2020 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), pp. 112-114, Sep. 2020.

[3] J. Temga, K. Edamatsu, M. Motoyoshi, N. Suematsu, "A Compact 28GHz-Band 4x4 Butler Matrix Based Beamforming Antenna Module in Broadside Coupled Stripline," 15th European Conference on Antennas and Propagation (EuCAP2021), T02-A02-5, Mar. 2021.

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.

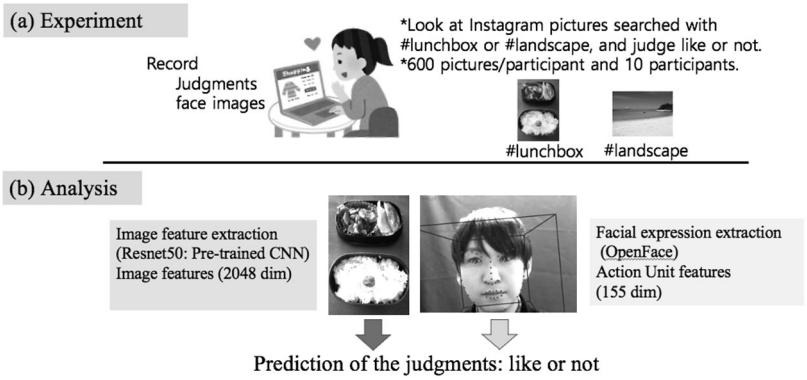


Fig. 1 Estimation of human preference judgments from facial expressions and image features.
(a) Subjective judgments for preference of images evaluation.
(b) Analyses of facial expression and image features for prediction of the preference judgements.

[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] S Shioiri, Y Sato, Y Horaguchi, H Muraoka, M Nihei, "Quali-informatics in the society with yotta scale data" IEEE International Symposium on Circuits and Systems (ISCAS), 1-4, 2021
[2] M Harasawa, Y Sawahata, K Komine, S Shioiri、Effects of content and viewing distance on the preferred size of moving images, Journal of vision 20 (3), 6-6
[3] N. Sasaki and N. Sakai: Effect of valance, arousal, and modality on cortical activities evoked by emotions. Tohoku Psychologica Folia, 79, 12-25, 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] Ryotaro Temma, Kazuki Takashima, Kazuyuki Fujita, Koh Sueda, Yoshifumi Kitamura: Enhancing Drone Interface Using Spatially Coupled Two Perspectives, Journal of Information Processing, Vol. 61, No. 8, pp. 1319-1332, 2020. (Recommended Paper) (in Japanese)
[2] Naoki Tsukahara: Fool the crow (カラスをだます), NHK Publishing, February 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

Suguru Kameda, Associate Professor (Project Leader)
Noriharu Suematsu, Professor
Takahiro Hanyu, Professor
Kazushi Ishiyama, Professor
Naofumi Homma, Professor
Qiand Chen, Professor
Mizuki Motoyoshi, Assistant Professor

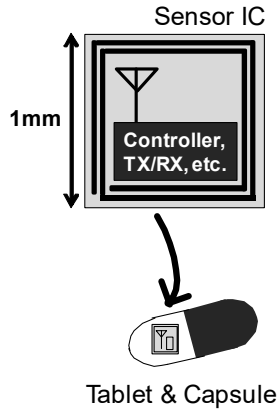


Fig.1 Battery-less tablet-pasting-type sensor

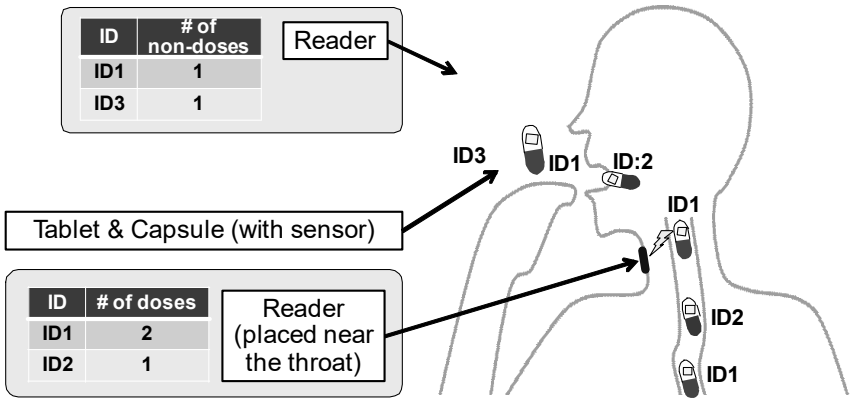


Fig.2 Safe medication management system

[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 designed low power ASK transmitter using SOI-process with high impedance substrate to increase the efficiency. In addition, the reflector under the loop antenna was employed to increase the radiated power toward the chip surface. As a result, the antenna gain is improved about 5dB in the Electro-Magnetic simulation.

[Papers]

[1] M. Motoyoshi, *et al.*, "Novel Dual-Band Wireless Communication System for Medical Usage", 2020 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), pp.130-132, Sep. 2020.

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: Yoichi Uehara, 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 reflect human intentions and 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 network.
3. Technical supports 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 web site.
・Developing and publishing videos containing the events and conferences associated with RIEC activities.
・Improving on the security measures of mobile device checked out of the RIEC premises.
・Operating the system with backup power sources under scheduled power shutdowns.

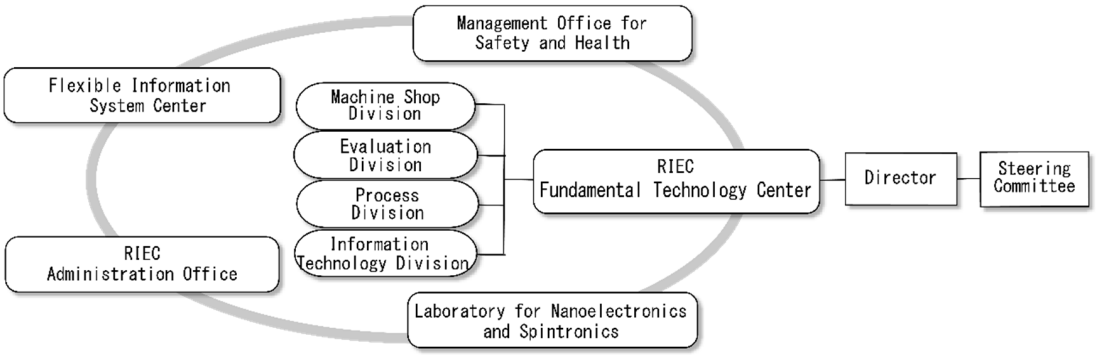
[Staff]

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

(2) Staff
Director (Professor): Atushi Ohori, Dr.
Professor*: Takuo Suganuma, Dr.
Associate Professor*: Gen Kitagata, Dr.
Technical Official: Masahiko Sato, Kenji Ota
Technical Official*:Yuko Maruyama
Technical Support Member: Mutumi Syutou, 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 97 machining products. About 13% of the requests were from outside the institute.

2. Evaluation Division

20 laboratories utilized the evaluation and measurement apparatuses for shared usage (the utilization time was 3,906 hours). 2 glass processing products were supplied. Technical assistance on the use of liquid helium was provided for 3 laboratories, and 559 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, 224 Electron-beam lithography products, 21 photomasks and 8 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, Masahiko SATO, 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 continued 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 2020, 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. In this year, we supported the JST Sato CREST project, organized a special session on brain-type hardware in the JNNS National Conference, and participated in the thematic program “Designing the Human–Centric IoT Society” of Tohoku Forum for Creativity, to propel collaborative researches on brainmorphic computing from broad perspective including brain science, spintronics, analog/digital integrated circuits, cultured neurocyte, and nonlinear complex dynamics. In addition, we supported an application to the JSPS KAKENHI (Grant-in-Aid for Transformative Research Areas).

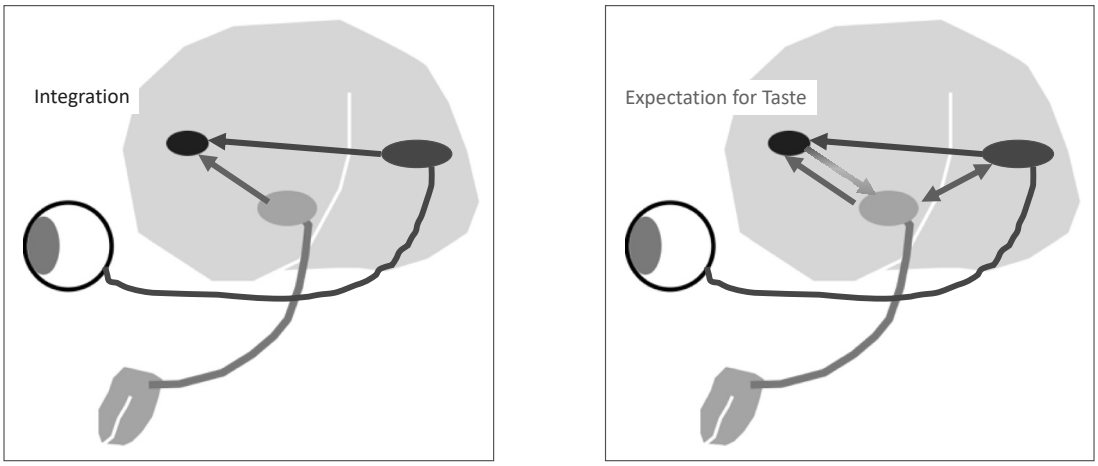
[Group of developing the AI clone system]

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) 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] F. Nakamura , N. Sakai , N. Sako , W. Tome & N. Kitai: Influence of dental education on the perception of overjet. *Orthodontic Waves*, 79,89-94, 2020 DOI: 10.1080/13440241.2020.1791649
[2] C. Fujii, T. Onuma, F. Nakamura , N. Sakai , N. Sako , W. Tome & N. Kitai: Influence of dental education on eye gaze distribution when observing facial profiles with varying degrees of lip protrusion. Journal of Dental Education, 85, 476-482, 2020 https://doi.org/10.1002/jdd.12471
[3] N. Sasaki and N. Sakai: Effect of valance, arousal, and modality on cortical activities evoked by emotions. Tohoku Psychologica Folia, 79, 12-25, 2021

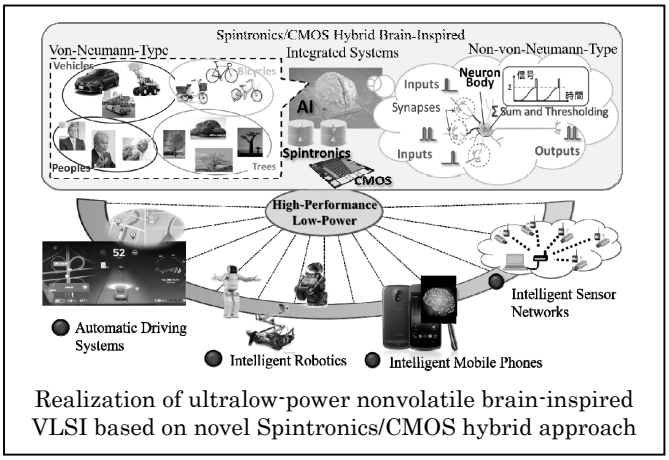
Spintronics/CMOS Hybrid Brain-Inspired Integrated Systems

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]

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 high-speed and high-precise multi-pin/multi-device VLSI measurement platform for Spintronics/ CMOS hybrid Brain-inspired chips based on both 300mm-wafer and package. Moreover, leveraging our well-equipped CMOS/MTJ hybrid VLSI design environment built-up by the last academic year, in the "von Neumann" approach, we successfully completed the design of our novel nonvolatile adaptive K-means unsupervised learning processor and nonvolatile FCNN object detection processor under 55nm-CMOS/5Xnm-pMTJ hybrid technology. On the other hand, in the "non-von Neumann" approach, we focused on SNN architecture and finished the design of our novel nonvolatile multi-core SNN recognition processor for ultralow-power object recognition accelerators in battery-driven edge devices.



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

[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] Tetsuo Endoh, et al., IEEE Symposium on VLSI Technology, Honolulu, HI, USA, 16-19 June 2020.
[2] Tao Li, Yitao Ma and Tetsuo Endoh, IEEE Access, Vol. 8, pp. 142931 - 142955, August 2020.
[3] Hui Shen, Yitao Ma and Tetsuo Endoh, SSDM2020, (Virtual), September 2020.
[4] Tetsuo Endoh, IEDM2020, (Virtual), December 12-18 2020.
[5] Hui Shen, Yitao Ma and Tetsuo Endoh, JJAP, Vol. 60, No. SB, pp. SBBL02, February 2021.
[6] Hui Shen, Yitao Ma and Tetsuo Endoh, Symposium for The Core Research Clusters for Spintronics, (Virtual), February 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: 44 (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 2020＞

・Promotion of world-leading research in spintronics

Excellent 11 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. In particular, additional budget was provided to the 5 most excellent proposals to accelerate the collaborations.

・Fostering excellent early-career researchers

Excellent early-career researchers, 6 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 FY2020 due to the influence of COVID-19. The 4th International Symposium for the Core Research Cluster for Spintronics was held via online in February, 2021 and the registrants were about 230 persons. The 2nd Tohoku-Lorraine Spintronics Workshop was held via online in March, 2021.

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: 79 (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 them into IoT / AI systems that require ultra-low power consumption.

＜Major activities in FY2020＞

CIES has managed the “CIES consortium” which consists of industry–academic collaborations, major national projects (CAO SIP 2nd, JST OPERA, JST NexTEP, JSPS Core-to-Core, NEDO Strategic Innovation Program for Energy Conservation Technologies, JAXA Space Exploration Innovation Hub, METI Tohoku Supporting Industry) and regional collaboration projects in cooperation with various international and domestic companies from material, equipment, devices and system aiming for the practical applications of innovative core technologies created by Tohoku University. The research and development field has been expanded from spintronics to AI hardware and power electronics, and the industry-academic collaborations have been significantly expanded from seven to eighteen. Companies participating in the CIES consortium have been steadily increasing and the consortium has grown into the world's largest one in this research field. 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)”.

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 succeeded in the demonstration operation of high-speed and highly reliable magnetic tunnel junction (MTJ) devices that enable automotive application of STT-MRAM, paving the way for expanding the application range from the IoT/AI to the automotive related fields. In addition, the world's first non-magnetic high-speed (350 picoseconds) rewrite spin-orbit torque (SOT) devices with 400°C thermal resistance and 10-year data retention characteristics have been developed. We have succeeded in integrating the SOT-MRAM cell with CMOS technology and demonstrating the operation of the SOT-MRAM chip, and have made great strides toward the practical application of high-speed non-volatile magnetic memory. In power electronics, taking advantage of the low loss and high-frequency operation of GaN on Si power devices, we have promoted higher functionality, smaller size and lighter weight of motor drive inverters and DC-DC converters. This will lead to the electrification of automobiles and the main power source of renewable energy, and will greatly contribute to decarbonization.

In addition, aiming to contribute to the development of the innovative integrated electronics business and further advancement of industry-academia collaboration, Power Spin Inc., a venture from Tohoku University founded by Prof. Tetsuo Endoh, is now in its third year, and with the support of a national project targeting small and medium-sized venture companies, it has been put into practical use based on the technology and know-how of this center. Furthermore, in 2020, this center was selected as the first regional open innovation base (International expansion type: Representative Prof. Tetsuo Endoh) under the METI's "Regional Open Innovation Base Selection System". In the future, while receiving support from the METI, we will contribute to the development of important industrial areas in Japan in response to the measures of Miyagi and Iwate prefectures.

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 OPERA research results at the disaster-resistant ICT research symposium. The research results produced by the promoted projects were presented in ROEC Homepage.

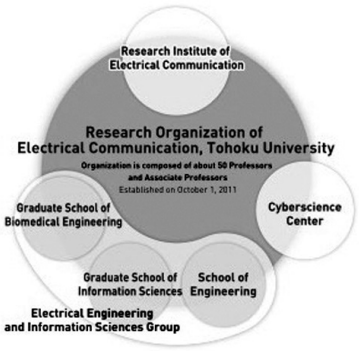


Fig.1 Research Organization of Electrical Communication.

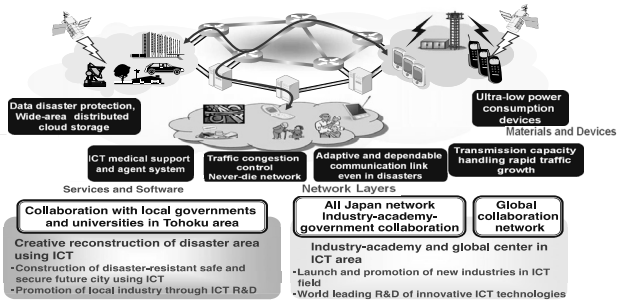


Fig.2 Overview of ICT Reconstruction Project.

[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] Fumiyuki Adachi, "Wireless Challenge for Beyond 5G", 16th EAI International conference on Collaborative Computing: Networking, Applications and Worksharing (EAI Collaborate Com 2020)
[2] T. Furuichi, Y. Gui, M. Motoyoshi, S. Kameda, T Shiba, N. Suematsu, "A Filter Design Method of Direct RF Undersampling On-Board Receiver for Ka-Band HTS," IEICE Trans. Commun., vol. E103-B, no.10, pp.1078-1085, Oct. 2020.
[3] T. Otsuji, K. Iwatsuki, H. Yamada, and M. Yashima, "Concept of resilitent electric power and information communication technology (R-EICT) converged network systems based on overall optimization of autonomous decintralized cooperative control of DC microgrids," ISGT-NA: IEEE PES (Power & Energy Society) Innovative Smart Grid Technologies Conference North America, Washington D.C., USA, online web, Feb. 15-18, 2021. DOI: 10.1109/ISGT49243.2021.9372169.

Center for Spintronics Research Network (CSRN)

＜About the Center＞

Establishment：April 1, 2016

Organization：Director: Koki Takanashi (Professor, IMR)
Number of academic members: 64 (including 2 full-time members 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 2020＞

・Cooperative Research Project

We adopt 64 cooperative research projects to promote collaborations with other spintronics researchers. The collaborators belong 41 institutions in Japan and 32 overseas institutions (in 13 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 2 international conferences, 5 domestic workshops, and 3 seminars/schools. A domestic workshop was held in June, 2020 to provide an opportunity of presentation for early-career researchers (about 60 oral presentations and more than 260 registrants).

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: 37 (RIEC, Graduate School of Engineering, CIES, 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 2020＞

1. We have started or continued 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 87 papers and 67 presentations (including 26 invited talks), and proceeded with 56 external grants in this year.
2. We organized “Symposium of Yotta Informatics – Research Platform for Yotta-Scale Data Science 2021”. We co-organized international symposiums "Tohoku U - NTU Symposium: When AI Meets Human Science" and "International Workshop on Emerging ICT". We also co-organized two IEICE conferences (EMM and HIP).
3. We started a new Cooperative Research Project U funded by RIEC Nation-wide Cooperative Research Projects and continued International Cooperative Research Project, proceeding cooperative research with an overseas research institute. To establish an open innovation platform for information-quality informatics studies, we continued an interdisciplinary project with the IT-21 Center in collaboration with Division for Interdisciplinary Advanced Research and Education.

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 2020＞

On April 1st, 2020, a new graduate student joined the MD program and the number of students became 30 in total. Most activities in FY2020, such as briefing sessions of internship, overviews and qualifying examinations were carried out via online. On August 6th, 2020, a tea party was held via online in order to provide an opportunity for communications between students. Total 12 participants including the students and staffs reported their present situation and exchanged information regarding upcoming activities of the MD program. A student of the MD program received the 11th JSPS *Ikushi* Prize on January 28th, 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 2020＞

Although most seminars and lectures were cancelled or postponed due to COVID-19 in FY2020, the 2nd Workshop “Math meets Quantum Materials” co-sponsored by Tohoku University and Riken was held via online on September 29-30, 2020 and an Assistant Professor of GP-Spin gave an invited talk in the Workshop. The 4th International Symposium for Core Research Cluster for Spintronics was held via online on February 24-25, 2021. After the invited talk by an Assistant Professor, 5 students gave oral presentations in the session organized by GP-Spin program. A series of 4 seminars “Spin-based Quantum Bits” was given by Prof. Thomas Schäpers (Forschungszentrum Jülich in Germany) via online in March, 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 60 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 cyber space in Society 5.0 with wide perspectives”.

＜Major Achievements in 2020＞

We have started a PBL (Project Based Learning) course, which is an original subject of the WISE program. This course is jointly developed and implemented by 12 sponsoring companies and the university faculty and forms the core of industry-university cooperative education. After the completion of the course, a symposium on the results of learning was held, and students made a presentation on their respective progress in this course. As a new approach to the internship program under the Corona disaster, the program students participated in internships at overseas and domestic companies by combining on-site training and online training. We also held six AIE lectures and two international symposia, in which prominent professors from Japan and abroad gave lectures on a wide range of topics, including basic techniques, applications, and issues in artificial intelligence electronics. We recruited and selected 20 new students (3 new M1, 11 new M2, and 6 new D1) for the third year (2021) of the program.

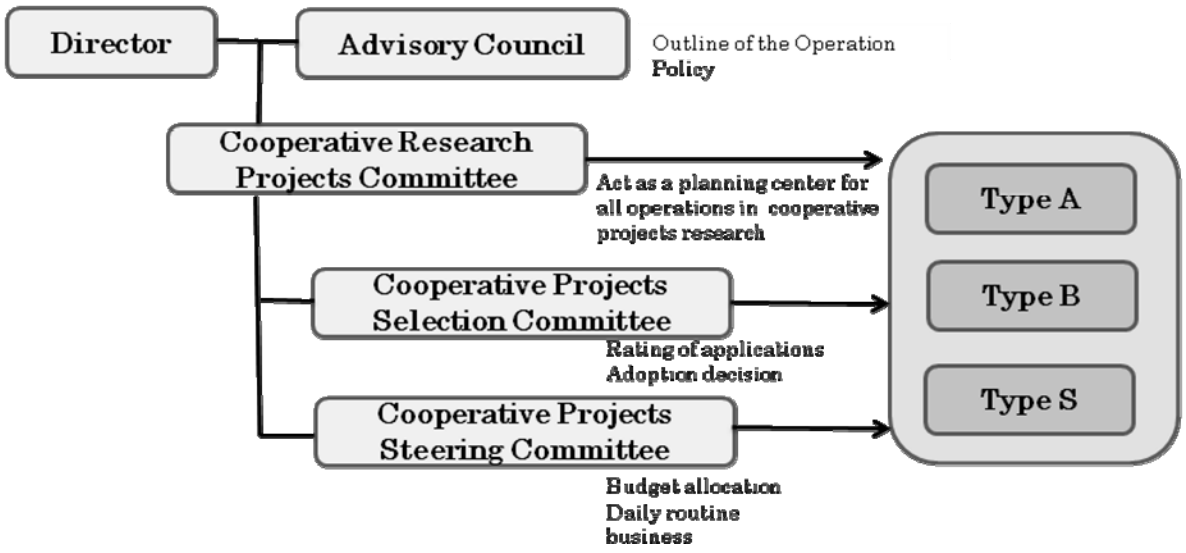
4. Nation-wide Cooperative Research Projects

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 2020

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
H30/A01	Study on advanced devices using operando spatiotemporal x-ray spectroscopy	**FUKIDOME Hirokazu** Research Institute of Electrical Communication, Tohoku University	**FUKIDOME Hirokazu**
H30/A02	Creation of Bio-Medical Devices Using Gas-Liquid Interfacial Plasmas	**KANEKO Toshiro** Graduate School of Engineering, Tohoku University	**HIRANO Ayumi**
H30/A05	Development of vibrational spectroscopy having high temporal and spatial resolution and its application to devices	**INAOKA Takeshi** Physics Program, Department of Physics and Earth Sciences, Faculty of Science, University of the Ryukyus	**UEHARA Yoichi**
H30/A06	Development of general control techniques of quantum systems	**FUKUHARA Takeshi** Center for Emergent Matter Science, RIKEN	**OTSUKA Tomohiro**
H30/A07	Control of spin state in semiconductor using photon-spin conversion	**ISHIHARA Jun** Department of Applied Physics, Faculty of Science, Tokyo University of Science	**KANAI Shun**
H30/A08	Nanoscale optical measurement and ultimate photoelectronic control of carbon nanomaterials	**KATANO Satoshi** Research Institute of Electrical Communication, Tohoku University	**KATANO Satoshi**
H30/A09	Informatics approaches in quantum devices	**SHIGA Motoki** Faculty of Engineering, Gifu University	**OTSUKA Tomohiro**
H30/A11	Energy Harvest applied Active Reflectarray for Mobile IoT search range expansion	**MARUYAMA Tamami** Department of Production Systems Engineering, National Institute of Technology, Hakodate College	**SUEMATSU Noriharu**
H30/A12	A Study of delay-sensitive access network configuration using widely frequency selectable optoelectronics devices	**YOSHIMOTO Naoto** Faculty of Science and Technology, Chitose Institute of Science and Technology	**OTSUJI Taiichi**
H30/A13	Single and coupled hard-type oscillators using resonant tunneling diodes and their application to THz signal processing	**MAEZAWA Koichi** Graduate School of Science and Engineering, University of Toyama	**OTSUJI Taiichi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
H30/A14	Loss Analysis of High Efficient Contactless Power Transmission	**INAMORI Mamiko** Department of Electrical and Electronic Engineering, Tokai University	**KAMEDA Suguru**
H30/A15	Study on method for modulating emotional experience by choice	**Takuya Onuma** Faculty of Humanity-oriented Science and Engineering, Kindai University	**SHIOIRI Satoshi**
H30/A16	Modulation of peripersonal space representation by self-motion information	**TERAMOTO Wataru** Graduate School of Social and Cultural Sciences, Kumamoto University	**SAKAMOTO Shuichi**
H30/A17	Study of difference between monaural listening and binaural listening on sound space perception	**MORIKAWA Daisuke** Faculty of Engineering, Toyama Prefectural University	**SAKAMOTO Shuichi**
H30/A18	Emergency vital measurement using flexible fiber electrode under electromagnetic environment	**TORIMITSU Keiichi** Research Organization of Electrical Communication, Tohoku University	**SUEMATSU Noriharu**
H30/A19	Research on gravimetric technology for monitoring volcanic activities using an optical fiber network	**ARAYA Akito** Earthquake Research Institute, The University of Tokyo	**YOSHIDA Masato**
H30/A20	Hardware Technology for Brain Computation	**SATO Shigeo** Research Institute of Electrical Communication, Tohoku University	**SATO Shigeo**
H30/A24	Research on development of flexible pressure sensors based on PVDF thin films	**TADAKI Daisuke** Research Institute of Electrical Communication, Tohoku University	**TADAKI Daisuke**
H30/A26	Basic study on Perceptual User Interfaces for Interaction with IoT	**OMATA Masaki** Graduate Faculty of Interdisciplinary Research, Yamanashi University	**KITAGATA Gen**
H30/A28	Brain-like Integrated System using Thin-Film Devices	**KIMURA Mutsumi** Faculty of Science and Technology, Ryukoku University	**HORIO Yoshihiko**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
H30/A29	Hardware security technologies for IoT	**OGUMA Hiroshi** Department of Electronics and Computer Engineering, National Institute of Technology, Toyama College	**HOMMA Naofumi**
H30/A30	Advanced IoT Infrastructure Based on Intelligent Edge	**SATO Fumiaki** Faculty of Science, Toho University	**OHORI Atsushi**
H30/A32	A Malware Detection System for Secure Campus BYODs	**SATOH Akihiro** Information Science Center, Kyushu Institute of Technology	**KITAGATA Gen**
H30/A33	Research of human life support based on agent IOT	**UCHIYA Takahiro** Information Technology Center, Nagoya Institute of Technology	**SAKAMOTO Shuichi**
H30/A34	Development of Metal Source/Drain CMOS on Ge-on-Insulator	**Hiroshi Nakashima** Global Innovation Center, Kyushu University	**SAKURABA Masao**
H30/A37	Research of on-chip terahertz antenna for ultra-wideband communication	**KANAYA Haruichi** Graduate School of Information Science and Electrical Engineering, Kyushu University	**SUEMATSU Noriharu**
H30/A38	Millimeter-wave array antenna using multi-layered substrate	**Satoshi Yoshida** Research Field in Engineering, Science and Engineering Area, Research and Education Assembly, Kagoshima University	**MOTOYOSHI Mizuki**
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/A02	Fabrication of high performance quantum device with atomically thin layered materials	**KATO Toshiaki** Graduate School of Engineering, Tohoku University	**OTSUKA Tomohiro**
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**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
H31/A05	Dynamics of spin-orbit torque induced switching of metallic antiferromagnet/non-magnet 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	**SHINJI Isogami** 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** Oxide Nanophysics Group, Catalan Institute of Nanoscience and Nanotechnology	**UEHARA Yoichi**
H31/A10	Study of ferromagnetic resonance induced by spin orbit torque and the phase rockling via spin waves for microwave oscillators excited by dc currents	**KODA Tetsunori** General Education Division, National Institute of Technology, Oshima College	**HASHI Shuichiro**
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**
H31/A14	Pre-verbal infant learning: Infants' preference and understanding from eye movements and pupil dilation	**LAU Esther** Department of Psychology, Hong Kong Educational University	**TSENG Chia-huei**
H31/A16	Improvement of outdoor mass notification sound systems by reconstructing speech structures	**CUI Zhenglie** Media Informatics , Aichi University of Technology	**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	**KAMEDA Suguru**
H31/A22	Interactive Content for Emergent Users	**JOSHI Anirudha** IDC School of Design, IIT Bombay	**KITAMURA Yoshifumi**
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	**MOTOYOSHI Mizuki**
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**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
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**
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	**KAMEDA Suguru**
R02/A08	Study on Electromagnetic Crosstalk Suppression in Mobile Devices Using Negative Magnetic Permeability Materials	**MUROGA Sho** Graduate School of Engineering Science, Akita University	**HASHI Shuichiro**
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**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R02/A13	Ultra-low-latency video coding for 8K high resolution image sencing	**Matsumura Tetsuya** College of Engineering, Nihon University	**OTSUJI Taiichi**
R02/A14	Development of Wireless Massive Connect IoT	**OGUMA Hiroshi** Department of Electronics and Computer Engineering, National Institute of Technology, Toyama College	**KAMEDA Suguru**
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/A17	HyperCubeHarmonic: A Conceptual Complete and Consistent Model to Control Multiple Dimensional Information of Music	**KITAMURA Yoshifumi** Research Institute of Electrical Communication, Tohoku University	**KITAMURA Yoshifumi**
R02/A18	Modeling the Japanese-Taiwanese racial effect in facial expression recognition	**CHEN Chien-Chung** Department of Psychology, National Taiwan University	**TSENG Chia-huei**
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	Direction dependence in the acoustical transfer function of human pinna	**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**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
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	**KAZUYUKI Fujita**
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**
R02/A26	Implicit non-verbal behaviors and brain communications	**TSENG Chia-huei** Research Institute of Electrical Communication, Tohoku University	**TSENG Chia-huei**
R02/A27	Multilingual study of cultural and individual differences in color lexicon	**TOKUNAGA Rumi** College of Liberal Arts and Sciences, Chiba University	**KURIKI Ichiro**
R02/A28	Gaze Visualization in Cooperative Work	**KIYOKAWA Kiyoshi** Graduate School of Science and Technology, Nara institute of science and technology	**KITAMURA Yoshifumi**
R02/A29	Investigating cultural-background effect on auditory selective attention processes	**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	**KEI Ishii** 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**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R02/A33	Research for In-Storage/Memory Computing Platform for Brain Neuro-Science	**TANAKA Yoichiro** Research Institute of Electrical Communication, Tohoku University	**TANAKA Yoichiro**
H30/B04	Formation of spatial and temporal structures and various reactive fields in plasma flows	**ANDO Akira** Graduate School of Engineering, Tohoku University	**ISHIYAMA Kazushi**
H30/B06	Research and development of optical space mode	**HAMAMOTO Kiichi** Faculty of Engineering Sciences, Kyushu University	**YOSHIDA Masato**
H30/B07	Functionalization of oxide surfaces and its application to nanodevices	**HIROSE Fumihiko** Graduate School of Science and Engineering, Yamagata University	**HIRANO Ayumi**
H30/B08	Establishment of information science approach and psychological verification method for intellectual productivity acquisition in group discussion	**ITOH Yuichi** Graduate school of Information Science and Technology, Osaka University	**TAKASHIMA Kazuki**
H30/B12	Establishments of Optimal Design and High-Efficiency Control Scheme for High-Frequency Wireless Power Transfer Systems	**SEKIYA Hiroo** Graduate School of Engineering, Chiba University	**HORIO Yoshihiko**
H30/B13	High-dimensional neural dynamics to develop next-generation neural hardware	**HIROSE Akira** Graduate School of Engineering, Tokyo University	**SATO Shigeo**
H30/B14	Future Office Space and Interaction	**KAZUYUKI Fujita** Research Institute of Electrical Communication, Tohoku University	**KAZUYUKI Fujita**
H30/B17	Development of Swarm Intelligence Optimization based on Nonlinear Dynamical Systems Theory and Its Application	**JINNO Kenya** Faculty of Knowledge Engineering, Department of Information and Communication Engineering, Tokyo City University	**HORIO Yoshihiko**
H30/B18	Empirical Research on Infrastructurization of Ubiquitous Computing	**MURAO Kazuya** College of Information Science and Engineering, Ritsumeikan University	**KITAGATA Gen**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
H30/B20	Understanding the brain mechanisms of mind""	**TSUTSUI Ken-Ichiro** Graduate School of Life Sciences, Tohoku University	**SHIOIRI Satoshi**
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**
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	**MOTOYOSHI Mizuki**
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/B05	HCI Research Community Development in Asia	**KITAMURA Yoshifumi** Research Institute of Electrical Communication, Tohoku University	**KITAMURA Yoshifumi**
H31/B06	Visual KANSEI mechanisms for SHITSUKAN and color perception	**OKAJIMA Katsunori** Faculty of Environment and Information Sciences, Yokohama National University	**KURIKI Ichiro**
H31/B08	Research and Development of UAVs UI/UX and its applications for stimulating region community/social implementation	**SUEDA Koh** Smart System Institute, National University of Singapore	**KITAMURA Yoshifumi**
H31/B09	New development of practical research on microwave and laser-based synthetic aperture radar	**KOGI Yuichiro** Department of Engineering, Fukuoka Institute of Technology	**YASAKA Hiroshi**
H31/B10	Wide-area distributed cooperation of edge computing infrastructure and its international development	**KASHIWAZAKI Hiroki** Center for Cybersecurity Research and Development, National Institute of Informatics	**KITAGATA Gen**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
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	**KAZUYUKI Fujita** Research Institute of Electrical Communication, Tohoku University	**KAZUYUKI Fujita**
H31/B13	Spin-orbit dynamics and its manipulation in solids	**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**
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: 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**
H31/B19	Securing IoT devices against EM Fault Injection	**VERBAUWHEDE Ingrid** Electrical Engineering, COSIC research group, KU Leuven	**HOMMA Naofumi**
R02/B01	Research on magnetic devices for advanced information system by controlling multiscale structure of magnetic material	**IKEDA Shinji** Faculty of Production Systems Engineering and Sciences, Komatsu University	**ISHIYAMA Kazushi**
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**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R02/B03	Layerless Design of Future Wireless Communications and Its Applications	**ISHIBASHI Koji** Advanced Wireless and Communication Research Center, The University of Electro-Communications	**KAMEDA Suguru**
R02/B04	Research on Wireless Technologies for the Beyond-5G System	**KUKI Takao** School of Science and Engineering, Kokushikan University	**SUEMATSU Noriharu**
R02/B05	Attentive Search: Theory and Application	**TSENG Chia-huei** Research Institute of Electrical Communication, Tohoku University	**TSENG Chia-huei**
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/B08	Control principle of joint action robot with human	**YAMAMOTO Yuji** Research Center of Health, Physical Fitness, and Sports, Nagoya University	**KANO Takeshi**
R02/B09	Study of designing interaction for coexisting with crows	**SUEDA Koh** Media Science Laboratory, Digital Hollywood University	**KITAMURA Yoshifumi**
R02/B10	A study on design principle inspired by adaptive and reflective behavior of animals	**ISHIKAWA Masato** Graduate School of Engineering, Osaka University	**ISHIGURO Akio**
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/B13	Cognition-Aware-Systems for Improving Human Performance	**Tag Benjamin** Melbourne School of Engineering, School of Computing and Information Systems, The University of Melbourne	**KITAMURA Yoshifumi**
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**
R 02/S1	Establishment for innovative coherent wave technology and its applications	**Mimura Hidenori** Research Institute of Electronics, Shizuoka University	**YASAKA Hiroshi**
H30/SI1	AI and Human Studies	**Su-Ling Yeh** AI and Advanced Robotics Center, Institute Graduate School National Taiwan University	**SHIOIRI Satoshi**
R 02/U01	Investigating usage of nonverbal information for online classes	**Shioiri Satoshi** Research Institute of Electrical Communication, Tohoku University	**SHIOIRI Satoshi**
R 02/U02	AI of Nonverbal Information to Realize Rich Inter-personal Communication	**Kitamura Yoshifumi** Research Institute of Electrical Communication, Tohoku University	**KITAMURA Yoshifumi**

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.

Symposium In Past

	Title	Date
1	Quantum Electronics of Liglht Waves and Micro Waves	Feb. 6- 8, 1964
	Magnetic Recording	Feb.14-15, 1964
2	Ultra-High Frequency Acoustelectronics	Feb.11-12, 1965
3	Artificial lntelligence	Mar. 8- 9, 1966
4	Thin Film Electronics	Jan.26-27, 1967
5	Crystal Growth	Dec. 19-20, 1967
6	1968 Sendai Svmoosium on Acoustelectronics	Aug.19-20, 1968
7	Current Status and Future Trends of Superconductivitv	Jan.22-24, 1970
8	Soeech Information Processing	Feb.24-26, 1971
9	Surface Acoustic Wave Technology	May.25-26, 1972
10	Liquid Crystals ·Their Molecular Orientations and Application to Display Devices	Dec.13-14, 1974
11	Computer Network	Mar.17-18, 1975
12	The Memorial Symposium on the 40th Anniversarv of the Foundation of RIEC	Sep.25-26, 1975
13	Application of Amorphous Ferromagnetic Materials	Mar.10-11, 1977
14	Stoichiometry of Compound Crystals	Nov.24-25, 1977
15	Submillimeter Waves	Nov.16-17, 1978
16	Solid State Chemical Sensors	Feb. 1- 2, 1980
17	Graph Theory and Algorithms	Oct.24-25, 1980
18	Perpendicular Magnetic Recording	Mar.11-12, 1982
19	Approach to Optical Computer	Mar.10-11, 1983
20	Plasma Non-Linear Phenomena - Basic Problems for Fusion Plasmas	Mar. 8- 9, 1984
21	New Computer Architecture	Jul.25-26, 1985
22	Guided Wave Technology and Its Application at Mid-Infrared	Mar.13-14,1986
23	Physics and Applications of Tunnelling Phenomena	Mar.12-14, 1987
24	Biomagnetics and Bioelectronics	Feb.26-27, 1988
25	Ultrasonic Electronics - New Applications of Piezoelectricity	Feb. 2- 3, 1989
26	Boundaries between Light and Electromagnetic Wave	Feb. 1-2, 1990

	Title	Date
27	Issues and Realization of Pattern Recognition and Understanding	Feb.28-Mar.1,1991
28	Discrete Algorithms	Oct.17-18, 1991
29	Perspective for New Computing Paradigm	Feb. 4- 5, 1993
	Current Status and Future Prospects of System Control	Mar. 3- 4, 1993
30	Future Prospects of Electron Beam Devices	Nov. 1- 2, 1993
31	Discharge and EMC	Dec.20-21, 1994
32	Statistical Physics and Information Science	Mar.22-23,1995
33	Photo-and Plasma-Excited Processes on Surfaces	Nov.30-Dec.1,1995
34	Nano Spinics and Power Electronics	Feb.15-16, 1996
35	Potential Formation and Related Nonlinear Phenomena in Plasmas	Sep.17-19, 1996
36	New Trend in Ultrasonic Measurements	Feb. 3- 4, 1997
37	Toward the Realization of the High-Definition Multi-Media Communication	Nov. 4- 6, 1997

International Symposium Organized by the Institute

	Title	Date
1	Intrinsic Josephson Effect and THz Plasma Oscillation in High T_c Superconductors	Feb.23-25, 1997
2	Design and Architecture of Information Processing Systems Based on The Brain Information Principle	Mar.16-18, 1998
3	Novel Techniques and Applications of Millimeter-Waves	Dec.14-16, 1998
4	The International Joint Conference on Silicon Epitaxy and Heterostructures	Sep.13-17, 1999
5	International Workshop on Photonic and Electromagnetic Crystal Structures	Mar.8-10, 2000
6	Physics and Application Spin Related Phenomena in Semiconductors	Sep.13-15, 2000
7	Rewriting in Proof and Computation	Oct.25-27, 2001
8	Nonlinear Theory and its Applications	Oct.28-Nov.1, 2001
9	New Paradigm VLSI Computing	Dec.12-14, 2002
10	Ultra High Density Spinic Storage System	Oct.23-24, 2003
11	3rd International Workshop on New Group IV (Si-Ge-C) Semiconductors	Oct.12-13, 2004
12	3rd International Workshop on High Freaqency Micromagnetic Devices and Materials (MMDM3)	Apr.11-12, 2005
13	4th International Conference on Silicon Epitaxy and Heterostructures (lCSl-4)	May 23-26, 2005
14	1st International WorkShop on New Group IV Semiconductor Nanoelectronics	May 27-28. 2005
15	GSIS International Symposium on Information Sciences of New Era: Brain, Mind and Society	Sep.26-27, 2005
16	The 1st RIEC International Workshop on Spintronics -Spin Transfer Phenomena-	Feb.8-9, 2006
17	4th International Workshop on High Frequency Micromagnetic Devices and Materials (MMDM4)	May 8,2006
18	4th International Conference on Physics and Applications of Spin-Related Phenomena in Semiconductors (PASPS-lV)	Aug.15-18,2006
19	2nd International Workshop on New Group IV Semiconductor Nanoelectronics	Oct.2-3,2006
20	2nd RIEC International Workshop on Spintronics	Feb.15-16,2007
21	Japan-China Joint Conference on acoustics, JCA2007	Jun.4-6,2007
22	International Conference on Discovery Science/ International Conference on Algorithmic Learning Theory	Oct.1-4,2007
23	The 3rd RIEC International Workshop on Spintronics	Oct. 31-Nov.1,2007
24	3rd International Workshop on New Group Ⅳ Semiconductor Nanoelectronics	Nov.8-9,2007
25	International Workshop on Nanostructures & Nanoelectronics	Nov.21-22,2007
26	The 18th International Symposium on Algorithms and Computation(ISAAC2007)	Dec.17-19,2007
27	International Interdisciplinary-Symposium on Gaseous and Liquid Plasmas (ISGLP 2008)	Sep.5-6,2008
28	4th International Workshop on New Group IV Semiconductor Nanoelectronics	Sep.25-27,2008

	Title	Date
29	The 4th RIEC International Workshop on Spintronics	Oct.9-10,2008
30	Global Symposium on Millimeter Waves 2009 (GSMM2009)	Apr.20-22,2009
31	Mini R.I.E.C. workshop on multimodal perception	Apr.24,2009
32	The 4th International Symposium on Ultrafast Photonic Technologies	Aug.4-5,2009
33	PIMRC2009 Personal Indoor and Mobile Radio Communications Symposium 2009	Sep.13-16,2009
34	2nd RIEC-CNSI Workshop on Nanoelectronics,Spintronics and Photonics (5th RIEC Symposium on Spintronics)	Oct.22-23,2009
35	International Workshop on the principles and applications of spatial hearing 2009 (IWPASH2009)	Nov.11-13,2009
36	5th International Workshop on New Group IV Semiconductor Nanoelectronics	Jan.29-30,2010
37	6th RIEC International on Spintronics	Feb.5-6,2010
38	2nd International Workshop on Nanostructure & Nanoelectronics	Mar.11-12,2010
39	2nd RIEC International Symposium on Graphene Devices (ISGD2010)	Oct.27-29,2010
40	9th Japan-Korea Symposium on Surface Nanostructures	Nov.15-16,2010
41	The 7th RIEC International Workshop on Spintronics	Feb.3-4,2011
42	The 42nd RIEC International Symposium 12th International Multisensory Research Forum (IMRF2011)	Oct.17-20,2011
43	The 8th RIEC International Workshop on Spintronics	Feb.2-3,2012
44	The Sixth International Symposium on Medical, Bio- and Nano-Electronics	Mar.8,2012
45	3rd International Workshop on Nanostructures & Nanoelectronics	Mar.21-22,2012
46	9th RIEC International Workshop on Spintronics	May 31-Jun.2,2012
47	The 1st International Workshop on Smart Technologies for Energy, Information and Communication (STEIC2012)	Oct.18-19,2012
48	Technical University of Dresden and Tohoku University Symposium 2012	Nov.2,2012
49	The 1st RIEC International Symposium on Brain Functions and Brain Computer	Nov.15-16,2012
50	Tohoku – Harvard Joint Workshop New Directions in Materials for anoelectronics,Spintronics and Photonics （10th RIEC International Workshop on Spintronics）	Jan.15-16,2013
51	11th RIEC International Workshop on Spintronics & 3rdCSISInternationalSymposiumonSpintronics-based VLSIs	Jan.31-Feb.1,2013
52	7th International Symposium on Medical, Bio- and Nano-Electronics	Mar.7,2013
53	6th Global　Symposium on Millimeter Wave 2013	Apr.22-23,2013
54	The 2nd RIEC International Symposium on Brain Functions and Brain Computer	Feb.21-22,2014
55	8th International Symposium on Medical,Bio- and Nano-Electro	Mar.6-7,2014

	Title	Date
56	5th International Workshop on Nanostructures and Nanoelectronics	Mar.6-7,2014
57	12th RIEC International Workshop on Spintronics	Jun.25-27,2014
58	The IEEE International Conference on Microwave Magnetics	Jun.29-Jul.2,2014
59	RIEC International Symposium on Perception and Communication	Jul.24,2014
60	APMC 2014(2014 Asia-Pacific Microwave Conference)	Nov.4-7,2014
61	The 3rd RIEC International Symposium on Brain Functions and Brain Computer	Feb.18-19,2015
62	International Symposium on Brainware LSI	Mar.2-3,2015
63	The 9th International Symposium on Medical, Bio- and Nano-Electronics	Mar.2-4,2015
64	The 6th International Workshop on Nanostructures and Nanoelectronics	Mar.2-4,2015
65	RIEC International Symposium on Vision and Cognition	Mar.20,2015
66	The 23rd Symposium of the International Colour Vision Society (ICVS 2015)	Jul. 3-7, 2015
67	RIEC International Symposium on Computer Graphics and Interactive Techniques: New Horizon	Sep. 26-27,2015
68	13th RIEC International Workshop on Spintronics	Nov. 18-20,2015
69	The 4th RIEC International Symposium on Brain Functions and Brain Computer	Feb. 23-24,2016
70	International Symposium on Brainware LSI	Feb. 26-27,2016
71	The 10th International Symposium on Medical, Bio- and Nano- Electronics	Mar. 1-3,2016
72	The 7th International Workshop on Nanostructures and Nanoelectronic	Mar. 1-3,2016
73	RIEC International Symposium on Ultra-Realistic Interactive Acoustic Communications 2016	May 20-21,2016
74	RJUSE TeraTech-2016: The 5th Russia-Japan-USA-Europe Symposium on Fundamental & Applied Problems of Terahertz Devices & Technologies (RIEC International Symposium on Fundamental & Applied Problems of Terahertz Devices & Technologies)	Oct.31-Nov.4,2016
75	Dependable Wireless Workshop 2016	Nov.9-10,2016
76	14th RIEC International Workshop on Spintronics	Nov.17-19,2016
77	The 4th RIEC International Symposium on Brainware LSI	Feb. 24-25,2017
78	The 5th RIEC International Symposium on Brain Functions and Brain Computer	Feb. 27-28,2017
79	RIEC International Workshop on Biomedical Optics 2017	Mar. 6,2017
80	The 8th RIEC International Workshop on Nanostructures and Nanoelectronics	Mar. 6-7,2017
81	RIEC Russia-Japan Joint International Microwave Workshop 2017	Oct.19-20,2017

	Title	Date
82	International Symposium on Photonics and Optical Communications （ISPOC 2017）	Oct.25-26,2017
83	RIEC International Symposium on Experience Design and Cognitive Science（The Second ACM SIGCHI Asian Symposium）	Nov. 18-19,2017
84	15th RIEC International Workshop on Spintronics	Dec.13-14,2017
85	The 6th RIEC International Symposium on Brain Functions and Brain Computer	Feb. 1-2,2018
86	The 5th International Symposium on Brainware LSI	Feb. 23-24,2018
87	The 9th International Workshop on Nanostructures and Nanoelectronics	Mar. 1-2,2018
88	Japan-Korea International Symposium on Magnetic Devices and Materials	Aug.24,2018
89	International Symposium on Universal Acoustical Communication 2018	Oct.22-24,2018
90	Asian Wireless Power Transfer Workshop (AWPT2018)	Nov. 2-4,2018
91	3rd Japan-EU Flagship Workshop on Graphene and Related 2D Materials	Nov. 19-21,2018
92	The 2nd Tohoku-NTU U Symposium on Interdisciplinary AI and Human Studies	Nov. 24,2018
93	The 14th International Conference on Intelligent Information Hiding and Multimedia Signal Processing (IIH-MSP2018)	Nov. 26-28,2018
94	RIEC International Symposium on Human-Computer Interaction （The Third ACM SIGCHI Asian Symposium）	Dec.12-13,2018
95	16th RIEC International Workshop on Spintronics	Jan.9-10,2019
96	The 7th RIEC International Symposium on Brain Functions and Brain Computer	Feb. 22-23,2019
97	The 6th International Symposium on Brainware LSI	Mar. 1-2,2019
98	The 10th International Workshop on Nanostructures and Nanoelectronics	Mar. 6-7,2019
99	12th Global Symposium on Millimeter Waves 2019 (GSMM2019)	May. 22-24,2019
100	The 16th International Workshop on Emerging ICT	Oct. 31- Nov. 2,2019
101	17th RIEC International Workshop on Spintronics	Dec. 3-6,2019
102	RIEC International Symposium on Human-Computer Interaction - Welcome CHI 2021, thinking of the future of HCI together -	Jan. 24-25,2020
103	The 8th RIEC International Symposium on Brain Functions and Brain Computer	Feb. 13-15,2020
104	The 9th RIEC International Symposium on Brain Functions and Brain Computer	Dec. 5,2020
105	RIEC International Symposium on Human-Computer Interaction	Jan. 24,2021
106	11th International Workshop on Nanostructures & Nanoelectronics	Mar. 1-2,2021
107	The 4th Tohoku - NTU Symposium on Interdisciplinary AI and Human Studies	Mar. 12-13,2021
108	Symposium of Yotta Informatics Research Platform for Yotta-Scale Data Science 2021	Mar. 23-24,2021
109	The 7th International Symposium on Brainware LSI	Mar. 31,2021

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. Hiroki Nishiyama
Manager	Prof. Hiroki Nishiyama

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

Sendai "Plasma Forum"	
Chair	Prof. Akira Ando
Manager	Prof. Toshiro Kaneko

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

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

Systems Control	
Chair	Prof. Makoto Yoshizawa
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	Assistant Prof. Ton That Loi

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	Associate Prof. Takeshi Kano

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

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, 2020

Professors	23
Associate Professors	21
Assistant Professors	22
Research Fellows	10
Specially Appointed Professors	2
Specially Appointed Assistant Professors	4
Administrative Staff（Including Limited Regular Employees）	29
Technical Staff（Including Limited Regular Employees）	16
Total	127

2. Researchers (FY2020)

Foreign Researchers	Visiting Professors	0
	Visiting Asociate Professors	0
Cooperative Researchers of Private Company etc		10
JSPS Research Fellowship for Young Scientists		10
JSPS Postdoctral Fellowship for Overseas Researchers		2
Invitation Fellowship for Research in Japan		0
Contract Researchers		3
Contract Trainees		1
Total		26

3. Students

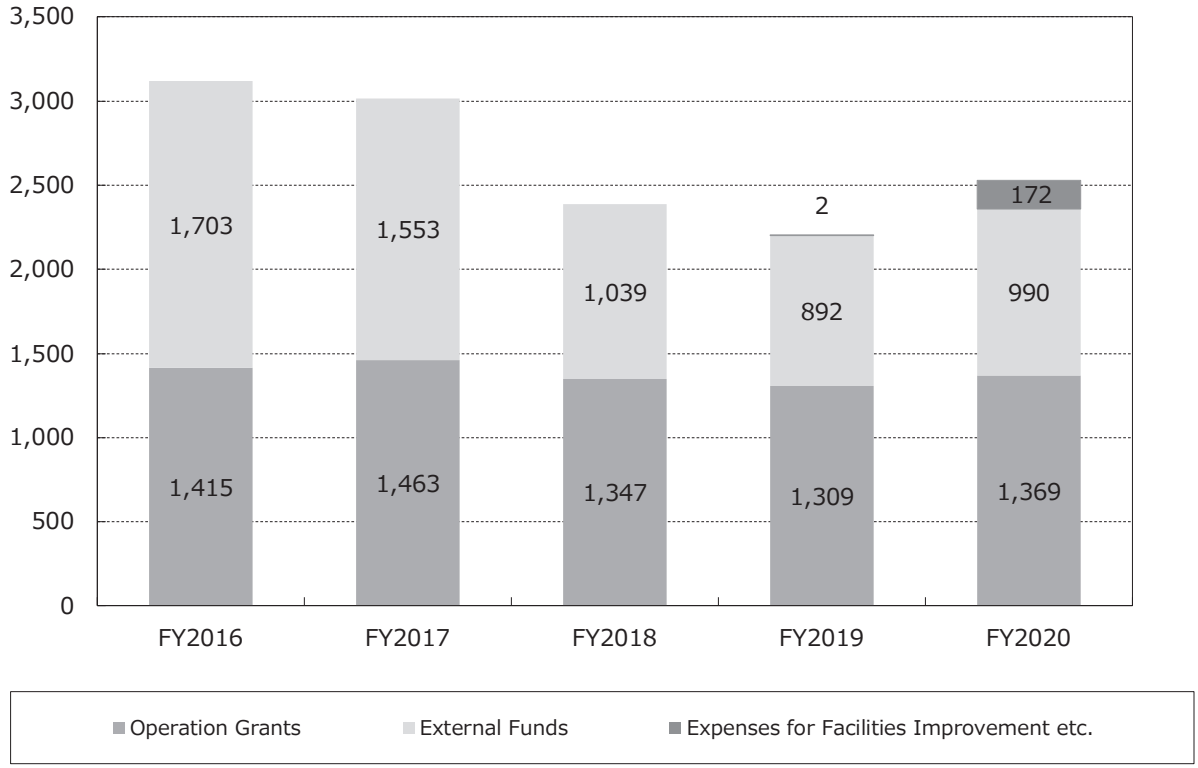
as of May 1, 2020

	School of Engineering	Graduate School of Information Science	Graduate School of Biomedical Engineering	RIEC	Total
Undergraduate Students	53 (1)				53 (1)
Master Course Students	92 (11)	40 (6)	9		141 (17)
Doctor Course Students	17 (6)	10 (4)	2		29 (10)
Institute Reserch Students				1	1
Total	162 (18)	50 (10)	11	1	224 (28)

4. Budget

Budget Shift

million yen



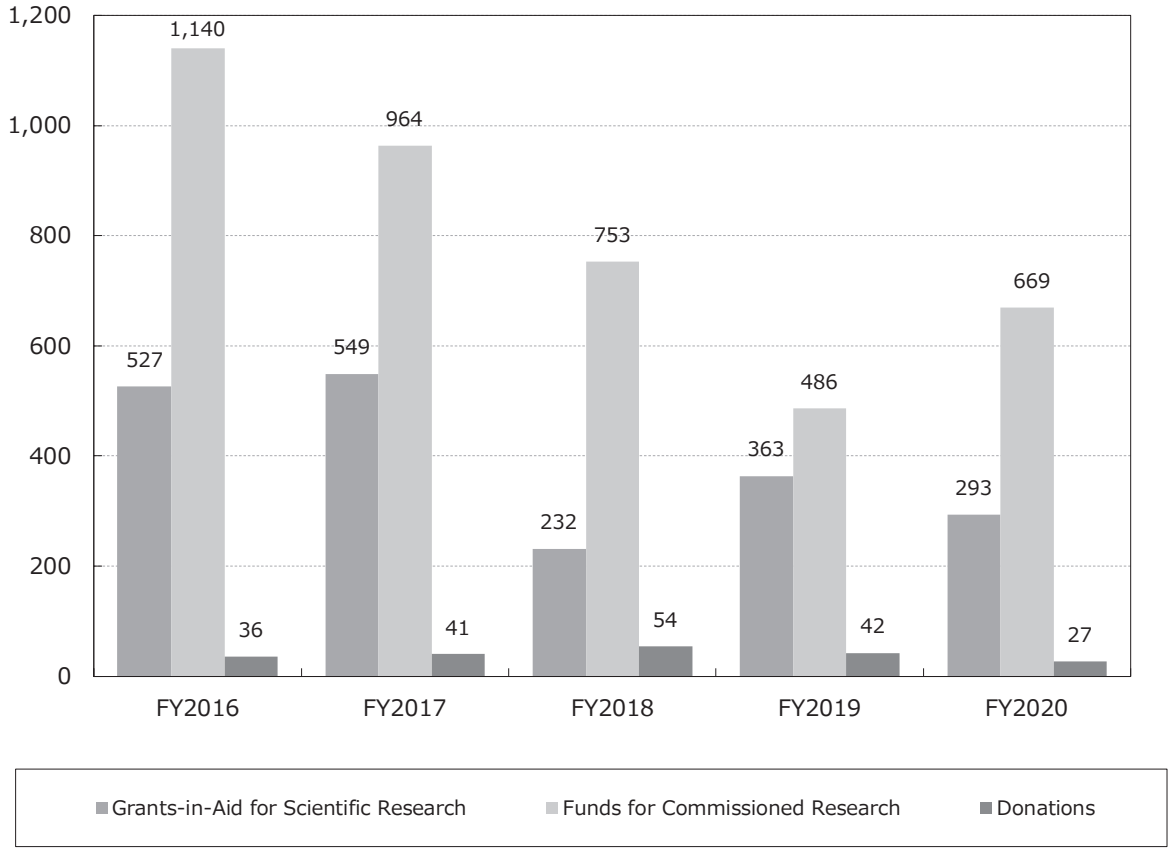
■ Budget Summary

thousand yen

Categories		FY2016	FY2017	FY2018	FY2019	FY2020
Operation Grants	Personnel Expenses	808,066	835,904	790,118	742,128	801, 695
	Non-Personnel Expenses	606,599	626,824	556,937	566,533	567, 249
Operation Grants Total		1,414,665	1,462,728	1,347,055	1,308,661	1,368,944
External Funds	Grants-in-Aid for Scientific Research	526,718	549,034	231,643	363,325	293, 404
	Funds for Commissioned Research	1,140,386	963,585	753,391	486,053	669, 454
	Donations	36,190	40,541	54,344	42,436	27, 200
	Indirect Expenses	244,413	220,733	134,311	155,852	172, 874
External Funds Total		1,703,294	1,553,160	1,039,378	891,814	990,058
Expenses for Reconstruction		0	0	0	1,936	172, 477
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	0	1,936	172,477
Total		3,117,959	3,015,888	2,386,433	2,202,411	2,531,479

External Funds

million yen



■ External Funds

thousand yen

Categories	FY2016	FY2017	FY2018	FY2019	FY2020
Grants-in-Aid for Scientific Research	526,718	549,034	231,643	363,325	293,404
Funds for Commissioned Research	1,140,386	963,585	753,391	486,053	669,454
Donations	36,190	40,541	54,344	42,436	27,200
Total	1,703,294	1,553,160	1,039,378	891,814	990,058

Annual Report 2020

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