Annual Report 2022

Research Institute of Electrical Communication
Tohoku University

Annual report of Research Institute of Electrical Communication 2022

Contents

1. Introduction

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

The Japan's Sixth Science and Technology Basic Plan aims to realize Society 5.0, 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, next-generation information communication, quantum computing, artificial intelligence, and multi-functional devices such as spintronics. It goes without saying that these research fields fall under the RIEC's scope of expertise and that the institute must play a leading role in furthering them. Meanwhile, universities are expected to conduct basic researches, some of which would create innovations that enriches the society. We have such examples in the history of our institute, such as Professor Junichi Nishizawa's three elements of optical communication and Professor Shunichi Iwasaki's perpendicular magnetic recording. They started related basic researches at RIEC, which opened new fields in ICT eventually. A more recent case is spintronics, which Professor Hideo Ohno has led from basic science to application to new devices. Magnetoresistive Random Access Memory (MRAM) is a device that uses the spintronics technology and is attracting public attention as the promising candidate of a critical and emerging device in the near future ICT. The environment in which Tohoku University and RIEC operate is constantly changing. Recognizing roles of university, RIEC must utilize resources efficiently to execute its mission and develop the environment for the purpose.

Since FY 2023, the institute's organizational structure has been organized into three units: three research divisions (Computing System Platforms

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

RIEC has also been certified by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) as a Joint Usage/Research Center for collaborative research in information science and technology. From the fiscal year 2022, RIEC has started the program's third term by the MEXT. As increase of importance of cooperation across different organizations, our role in advancing the information and communication community—both in Japan and overseas—will become increasingly important. To this end, we are collaborating on joint research projects with external researchers and engineers from industry, government, and academia in a systematic manner.

Overcoming the corona disaster, the importance of information communication is now attracting more and more attention. 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.

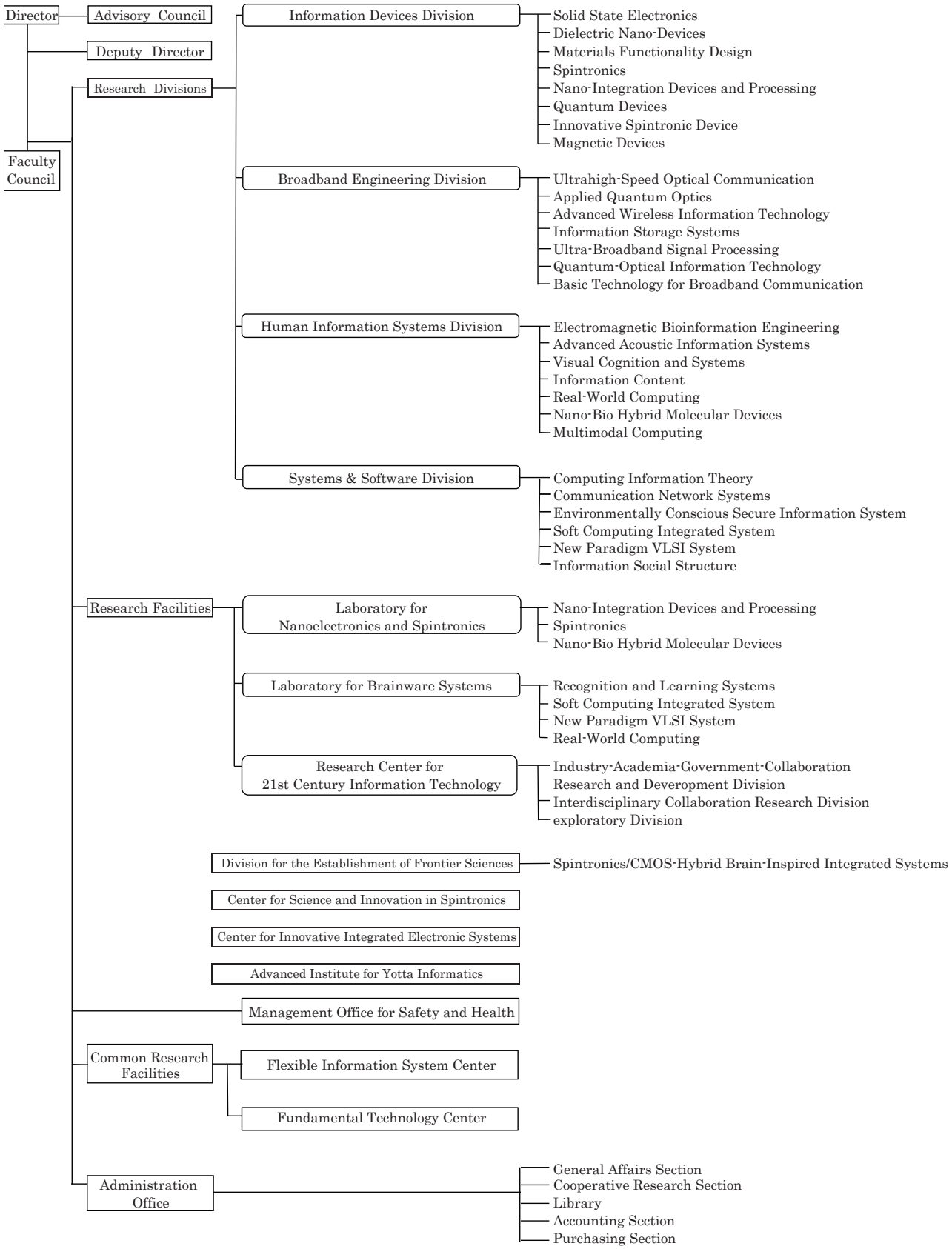
To contribute to the improvement of our research activities and support future developments, we publish this Annual Report every year to make our activities relating to research, education, and social contribution widely available for public scrutiny. This edition contains reports on a range of activities, 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.

2023

Takahiro Hanyu
Director, Research Institute of Electrical Communication

2. Organization Chart



3. Research Activities

Targets and achievements of the Information Devices Division

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

To achieve the goal, the following 7 laboratories are carrying out researches and developments.

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

The research target and the summary of activities of each sub-division in FY2022 are described in the following pages.

Solid State Electronics Laboratory

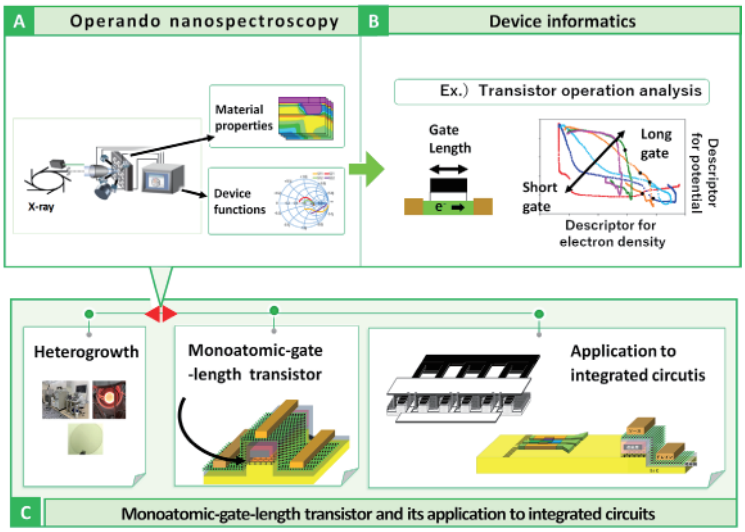
Creation of the ultimate transistor and its application to integrated circuits

Solid State Physics for Electroncis Hirokazu Fukidome, Associate Professor

[Research Target and Activities]

We aim at the ultimate transistor where the gate length is shortened down to monoatomic scale, and its application to integrated circuits. Simultaneously, we create device informatics (DI) which connect material properties with device functions by using bigdata taken by operando x-ray nanospectroscopies.

In 2022, we succeeded in establishing the fabrication process of monoatomic-length-gate by combining graphene growth method with 3D MEMS technologies. This enables to orthogonalize graphene 2D semiconductors. Furthermore, we exploited DI, and discovered that the material properties which governs device functions varies with the gate length.



[Staff]

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

[Profile]

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

[Papers]

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

[2] T. Otsuji, S. A. Boubanga-Tombet, A. Satou, D. Yadav, **H. Fukidome**, T. Watanabe, T. Suemitsu, A. A. Dubinov, V. V. Popov, W. Knap, V. Kachorovskii, K. Narahara, M. Ryzhii, V. Mitin, M. S. Shur, and V. Ryzhii,, "Graphene-based plasmonic metamaterial for terahertz laser transistors", Nanophotonics, 11 (2022), 1677-1696.

[3] T. Otsuji, S. A. Boubanga-Tombet, A. Satou, D. Yadav, **H. Fukidome**, T. Watanabe, T. Suemitsu, A. A. Dubinov, V. V. Popov, W. Knap, V. Kachorovskii, K. Narahara, M. Ryzhii, V. Mitin, M. S. Shur, and V. Ryzhii, Fast and sensitive terahertz detection with a current-driven epitaxial-graphene asymmetric dual-grating-gate field-effect transistor structure, APL Photonics, 7 (2022) 126101.

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Dielectric Nano-Devices

Research on Dielectric Nano Science and Technology

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.

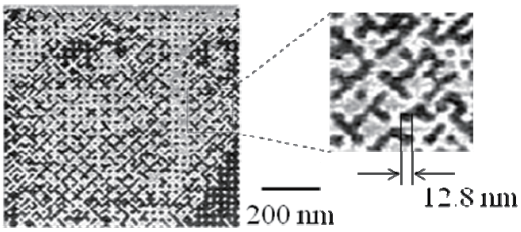

Fig.1 Digital bit data written on ferroelectric single crystal with the areal recording density of 4 Tbit/inch^2.

Major achievements of studies in 2022 are as follows: (1) We established the basis for machine learning analysis of hyperspectral image datasets on nanoscale ferroelectric domain inversions obtained using local C-V mapping methods. We applied this method to the quantitative evaluation of the degree of influence of grain boundaries on the domain inversion in HfO_2-based ferroelectric thin films. (2) We extended the time-resolved SNDM based local CV profiling method to evaluate the spatial fluctuations of properties of semiconductor-insulator interfaces at a nanoscale level. We applied the proposed method to various interfaces such as SiO_2/SiC, Al_2O_3/diamond, and Al_2O_3/GaN for power electronics.

[Staff]

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

[Profile]

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 noncontact scanning nonlinear dielectric microscopy and potentiometry with atomic-resolution. He also works on the development of multifunctional time-resolved scanning probe microspectroscopy system for 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] K. Yamasue and Y. Cho, Mater. Sci. Forum, Vol. 1062, pp. 335-340 (2022)
[2] Y. Hiranaga *et al.*, Jpn. J. Appl. Phys., Vol. 61, SN1014(1-8) (2022)
[3] K. Yamasue and Y. Cho, Microelectron. Reliab. Vol. 135, 114588(1-8) (2022)

Materials Functionality Design

Computational Design of Functional Materials for Information Devices

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

[Research Target and Activities]

Our research targets are as follows: (1) theoretical analyses of quantum phenomena in materials for advanced information devices, (2) computational design of new materials possessing novel functionalities for improvement of device performance, and (3) development of new design procedures based on large-scale computational simulation and data-driven approaches.
Our research activities in FY 2022 are as follows:

(1) Design of novel magnetic semiconductors by scale-bridged simulations

We explored magnetic semiconductors possessing high Curie temperature by using exhaustive *ab initio* calculations. We found promising candidates, Cr-doped AlP and AlAs, in which the Cr atoms exhibit attractive interactions and form nanoclusters upon annealing. Moreover, we revealed that the density, size, and shape of Cr nanoclusters can be controlled and thus the Curie temperature can be optimized by adjusting the annealing conditions [1].

(2) *Ab initio* electronic structure calculations of topological materials

We investigated the electronic structure of thermopower materials $YbMg_2Bi_2$ and $CaMg_2Bi_2$ by using *ab initio* calculations and angle-resolved photoemission spectroscopy. The experimental results can be reproduced by considering spin-orbit coupling and Coulomb repulsion between 4f electrons at the Yb site. Holes resulting from vacancies play an important role in the transport properties of these materials and thus electron doping is efficient to observe the topological surface states [2].

(3) Hydrogen at terapascal pressures

Stable structures of hydrogen at terapascal pressures are investigated by using ab initio calculations. Chief attention is paid to the effects of proton zero-point energy on structures, where anharmonicity is analyzed with the use of the self-consistent harmonic approximation. The results suggest that several isotropic structures have low enthalpies above 3.9 TPa, and that the anharmonicity significantly affects the phase diagram of hydrogen even at such high pressures

[Staff]

Professor: Masafumi Shirai, Dr.
Associate Professor: Kazutaka Abe, Dr.
Assistant Professor: Masahito Tsujikawa, Dr.
Assistant Professor: Hikari Shinya, Dr.
Assistant Professor: Tufan Roy, 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] H. Shinya, T. Kubota, Y. Tanaka, and M. Shirai, "Design of novel magnetic semiconductors by exhaustive first-principles calculations and scale-bridging simulations," Mater. Today Commun., Vol. 31, pp. 103604/1-8, 2022
[2] A. K. Kundu, T. Roy, S. Pakhira, Z.-B. Wu, M. Tsujikawa, M. Shirai, D. C. Johnston, A. N. Pasupathy, and T. Valla, "Topological electronic structure of $YbMg_2Bi_2$ and $CaMg_2Bi_2$," npj Quantum Mater., Vol. 7, pp. 67/1-9, 2022
[3] Z. Qiao, M. Tsujikawa, and M. Shirai, "The effect of chemical disorder on magnetic properties for FeNi and Fe_2Ni_2N alloys," J. Magn. Magn. Mater., Vol. 568, pp. 170362/1-8, 2023

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Spintronics

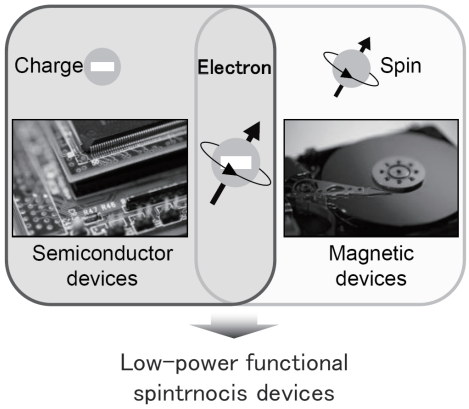
Advanced technology for spintronics-based devices

Nano-Spin Materials and Devices: Shunsuke Fukami, Professor
Functional Nano-Spin Devices: Shun Kanai, Associate 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 electrons and their spin states are controlled. We are also working on research and development of advanced technology for spintronics-based devices and unconventional computing, which offer high-performance and low-power information and communication technologies.

The outcomes in the last fiscal year include (1) the discovery of scaling law describing the phase coherence time of quantum state in solids, (2) the experimental determination of mathematical expression of thermally activated magnetization switching under magnetic fields and current, and (3) demonstration of high performance and low-power consumption of spintronic probabilistic computers.



[Staff]

Professor: Shunsuke Fukami, Ph. D.,
Associate Professor: Shun Kanai, Ph. D.,
Assistant Professor: 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 (2011). He received the JSAP Paper Award (2012), 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), Aoba Foundation Award (2017), Asian Union of Magnetics Societies, Young Researchers Award (2018), the Outstanding Research Award of the Magnetics Society of Japan (2018), the JSAP Outstanding Paper Award (2019), Marubun Research Encouragement Award (2021), InaRIS Research Fellow (2022), Achievement Award of the Magnetic Society of Japan, and JSPS Prize (2023).

Shun Kanai received Ph. D. degree from Tohoku University in 2014 and joined Tokou University (2014). He received the Tohoku University President's Award (2010), JSAP Young Scientist Presentation Award (2014), Student Award of RIEC Award, Tohoku University (2014), Young Scientist Award of Aoba Foundation (2015), Young Scientist Award of Funai Foundation (2016), Harada Young Research Award (2016), Young Scientist Award of Inoue Research Foundation (2017), Hiroshi Ando Memorial Award (2017), Young Scientists' Prize of Science and Technology by the MEXT (2023), and Young Scientists' Award of Honda Memorial Foundation.

[Papers]

[1] S. Kanai, F. J. Heremans, H. Seo, G. Wolfowicz, C. P. Anderson, S. E. Sullivan, M. Onizhuk, G. Galli, D. D. Awschalom, and H. Ohno, "Generalized scaling of spin qubit coherence in over 12,000 host materials," Proceedings of National Academy of Science of United States of America **119**, e2121808119(1)-(8) (2022).

[2] T. Funatsu, S. Kanai, J. Ieda, S. Fukami, and H. Ohno, "Local bifurcation with spin-transfer torque in superparamagnetic tunnel junctions," Nature Communications **13**, 4079(1)-(8) (2022).

[3] A. Grimaldi, K. Selcuk, N. A. Aadit, K. Kobayashi, Q. Cao, S. Chowdhury, G. Finocchio, S. Kanai, H. Ohno, S. Fukami and K. Y. Camsari, "Experimental evaluation of simulated quantum annealing with MTJ-augmented p-bits," (oral) 68th Annual IEEE International Electron Devices Meeting, 22.4.1 (2022).

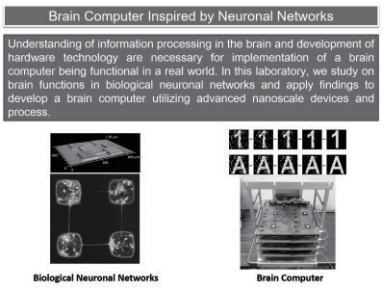
Nano-Integration Devices and Processing

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) A spiking neuron that reproduces various neural pulses and operates at extremely low power was implemented on an LSI, and a recurrent neural network was constructed using it and applied to reservoir computing. It has been confirmed by electrical measurements that time-series signals such as speech signal could be correctly classified. (2) To develop high-voltage and low-loss power semiconductor devices, double ion-implanted Al-gate 4H-SiC MOS transistors were fabricated utilizing high-temperature wet oxidation, and clear transistor-operation characteristics with low gate leakage were demonstrated even for gate length of 5 micron. (3) We developed defined neuronal networks with a modular design on high-density microelectrode arrays, using a surface coating protocol involving a cell-permissive hydrogel for secure attachment of a polydimethylsiloxane microfluidic film. The spontaneous neural activity recorded from these engineered networks demonstrated that the modular architecture enhances functional complexity by reducing excessive neural correlation between spatially separated modules.



Towards the Realization of a Brain Computer

[Staff]

Professor: Shigeo Sato, Dr.
Associate Professor: Masao Sakuraba, Dr.
Associate Professor: Hideaki Yamamoto, Dr.
Specially Appointed Assistant Professor: 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, S. Sato, Y. Yuminaka, Y. Horio, J. Madrenas “A fully Analog CMOS implementation of a two-variable spiking neuron in the subthreshold region and its network operation”, 2022 International Joint Conference on Neural Networks (IJCNN), 1-7, 2022.

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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 2022 are the following.

(1) Development of local measurement and control techniques

We developed electronic measurement and control methods of local electronic states in nanostructures utilizing semiconductor quantum dots. We improved the methods with high-frequency techniques and applied them to new materials.

(2) Measurement of local electronic states in nanostructures

We measured local electronic and spin states in nanostructures utilizing sensitive electronic measurement techniques. We revealed the detail of local electronic states in nanostructures and new materials [1, 2].

(3) Development of quantum devices and systems

We studied semiconductor quantum devices for future quantum information processing. We worked on state analysis and control of quantum devices to scale up the systems and new material-based devices [3].

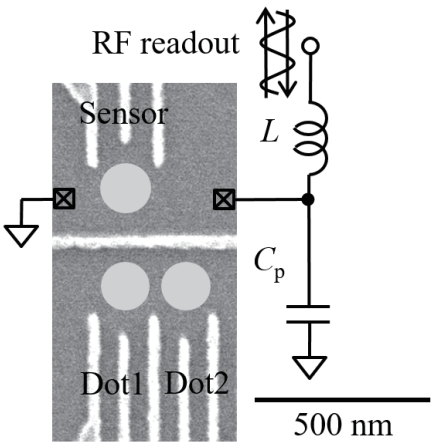

Figure: Scanning electron micrograph of a nanostructure device

[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, J. Igarashi, S. Iwakiri, T. Kitada, K. Hayakawa, B. Jinnai, T. Otsuka, S. Fukami, K. Kobayashi, and H. Ohno, "Nonlinear conductance in nanoscale CoFeB/MgO magnetic tunnel junctions with perpendicular easy axis", Physical Review B 107, 094436 (2023).

[2] T. Kato, T. Kitada, M. Seo, W. Okita, N. Sato, M. Shinozaki, T. Abe, T. Kumasaka, T. Aizawa, Y. Muto, T. Kaneko, and T. Otsuka, "Scalable fabrication of graphene nanoribbon quantum dot devices with stable orbital-level spacing", Communications Materials 3, 103 (2022).

[3] T. Otsuka, "Quantum dots in new materials for quantum devices", International Workshop of Spin/Quantum Materials and Devices, Sendai, Feb. 24, 2023.

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, by applying our coherently-linked optical and wireless transmission scheme with an injection-locked carrier frequency converter to a 28 GHz band in practical use for 5G, we successfully demonstrated a 16 Gbit/s, 256 QAM coherently-linked optical and wireless transmission over a 10 km fiber and 3 m wirelessly by using a microstrip antenna. We also achieved a 48 Gbit/s, 256 QAM coherently-linked transmission over a 10 km fiber and over 20 m wirelessly in the 61 GHz band by using a practical low profile planar antenna with a gain of 37 dBi.

(2) Applied Quantum Optics

Novel functional semiconductor photonic devices including photonic integrated circuits are being investigated to explore next-generation photonic network systems.
A study on ultra-high-speed semiconductor laser introducing hybrid modulation scheme was being continued. It was confirmed experimentally that the small signal E/O modulation bandwidth of the hybrid modulation semiconductor laser source can be enlarged up to 124 GHz by shortening its cavity length to 410 μm. Furthermore the study on compact and narrow linewidth semiconductor laser sources was also being proceeded by applying the optical negative feedback technology to the hybrid modulation laser. It was confirmed experimentally that phase noise reduction bandwidth can be enlarged by applying the optical negative feedback scheme to the laser. The maximum reduction ratio and -20-dB reduction bandwidth of power spectral density of frequency noise was estimated to be -40.4 dB and 1.6 GHz which is lager and wider than the optical negative feedback lasers with conventional DFB lasers.

(3) Advanced Wireless Information Technology

We are actively engaged in research work on wireless Internet of Things (IoT) technologies for next-generation wireless systems, which include terrestrial / satellite communications. The covered areas of us are all technical fields from the lower to higher layers, i.e., digital signal processing, RF/Mixed-signal device, antenna, transceiver, and subsystem technologies. This year, we have successfully developed a 4-elements 20GHz-band digital beam forming transmit antenna using 100GbE optical-fiber-feed 1-bit band-pass delta-sigma direct digital RF transmitter.

(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. This year, our research concentrated on heat-assisted magnetic recording (HAMR), with the aim of doubling the storage capacity. We have also been studying arrays of spintronic devices for use in artificial neural networks. We have constructed a "computational storage system" with unified 2PB storage and computation functions, and integrated the object distributed storage Ceph. By using visualization analytics of brain neuro structures, large scale data access performance was evaluated.

(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, a prototype field-effect transistor with a unique asymmetric double-grating gate structure using a monolayer of carbon atoms: graphene as a channel, and a new unipolar photothermoelectric terahertz detection mechanism involving only electrons was discovered, and high-speed, high-sensitivity terahertz wave detection was successfully achieved for the first time (press released on Dec. 2022). Second, regarding optical-to-wireless carrier frequency down-conversion devices (UTC-PD-integrated HEMT photonic double-mixers) required for realization of beyond-5G networks, we paid attention to a technique of generating low-noise, high-intensity optical signal input to a double-mixer and showed that the linear enhancement of the conversion gain with up to 10-dB enhancement is expected (received the Best Poster Paper Award at the IRMMW-THz 2023).

(6) Quantum-Optical Information Technology

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

In 2022, we have achieved (1) evaluation of error-disturbance uncertainty relation in Faraday measurement, (2) generation of spectrally factorable photon pairs via controlled quasi-phase-matched spontaneous parametric down-conversion, (3) development of ultra-low-loss, circuit photon memory (buffer), and (4) plasmon-enhanced single photon source coupled to an optical nanofiber.

Research Laboratory of Ultrahigh-Speed Optical Communication

Toward Innovative Optical Transmission from Backbone to Access Networks

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

[Research Target and Activities]

Advanced global ICT services such as ultrahigh-definition video transmission and ultra-realistic communication cannot be realized without high-speed and large-capacity optical transmission systems. At the same time, optical transmission schemes with high spectral efficiency are crucial in terms of the maximum utilization of limited bandwidth resources. In our laboratory, we are engaged in research on ultrahigh-speed optical transmission using optical time division multiplexing with a single-channel Tbit/s-class capacity, digital coherent QAM optical transmission, and high-speed and spectrally efficient optical transmission by combining these two approaches. With a view to supporting innovative new ICT services such as 5G and IoT, our goal is also to apply digital coherent transmission to access networks and mobile fronthaul, and to develop novel transmission schemes integrating optical and wireless communications. This year, by applying our coherently-linked optical and wireless transmission scheme with an injection-locked carrier frequency converter to a 28 GHz band in practical use for 5G, we successfully demonstrated a 16 Gbit/s, 256 QAM coherently-linked optical and wireless transmission over a 10 km fiber and 3 m wirelessly by using a microstrip antenna.

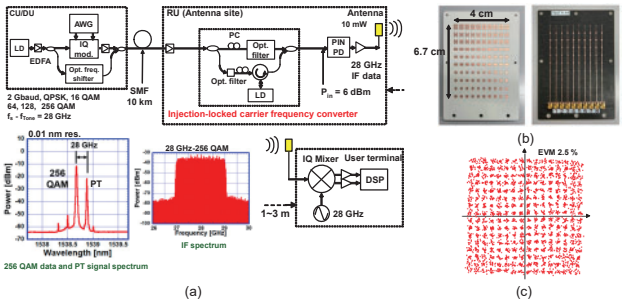

Fig. 1. Coherently-linked optical and wireless transmission using a 28 GHz band microstrip antenna

[Staff]

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

[Profile]

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

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

[Papers]

[1] K. Kasai, T. Kan, M. Yoshida, T. Hirooka, and M. Nakazawa, "Broadband injection-locked homodyne receiver for digital coherent transmission using a low Q Fabry-Perot LD," Opt. Express, vol. 30, no. 8, pp. 13345-13355, April (2022).
[2] K. Kimura, M. Yoshida, K. Kasai, T. Hirooka, and M. Nakazawa, "Experimental and Numerical Analysis of Ultrahigh-Speed Coherent Nyquist Pulse Transmission with Low-Nonlinearity Dispersion Compensator," IEICE Trans. Comm., vol. E105-B, no. 9, pp. 1014-1022, Sep. (2022).
[3] M. Nakazawa, K. Kasai, M. Yoshida, and T. Hirooka, "Optical and Wireless Linked Fully Coherent Access System toward Next Generation RAN," IEICE Trans. Electron. (in Japanese), invited paper, vol. J105-C, no. 11, pp. 315-328, Nov. (2022).

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Applied Quantum Optics

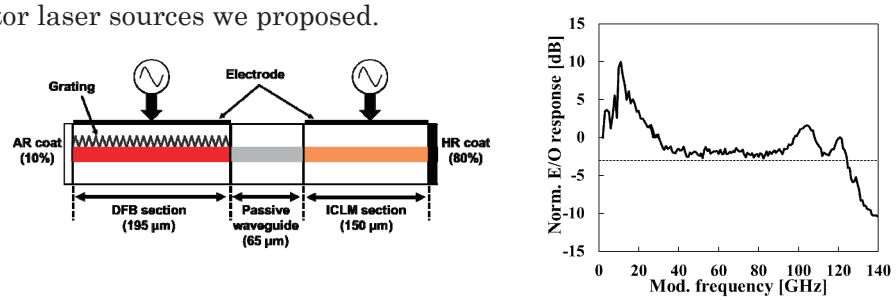
Research on Innovative Highly Functional Photonic Semiconductor Devices

Highly Functional Photonics	Hiroshi Yasaka, Professor
High accuracy optical measurement	Masato Yoshida, Associate Professor
Emerging semiconductor light source	Nobuhide Yokota, 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 with total cavity length of 410 μm has wide modulation bandwidth up to 124 GHz. Furthermore high SNR FMCW LiDAR system is realized by applying compact and narrow linewidth optical negative feedback semiconductor laser sources we proposed.



Schematic structure of short cavity hybrid modulation laser (left) and its measured frequency response (right).

[Staff]

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

[Profile]

Hiroshi Yasaka received Ph.D. degree in electronic engineering from Hokkaido University in 1993. In 1985 he joined Nippon Telegraph and Telephone (NTT) Corporation. From 2008 he has been a professor of Research Institute of Electrical Communication, 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.

Nobuhide Yokota received Ph.D. degree in engineering from Nara Institute of Science and Technology in 2014. In 2014, he joined the Research Institute of Electrical Communication, Tohoku University. He is currently an Associate Professor of the Institute.

[Papers]

[1] H. Yasaka, W. Kobayashi and N. Yokota, "Numerical Analysis of 100-Gbit/s Dynamic Single-Mode Operation of Hybrid-Modulation Semiconductor Lasers," IEEE Journal of Quantum Electronics, vol. 59, No. 2, 1200107, 2023.

[2] T. Shima, N. Yokota, M. Yoshida, W. Kobayashi and H. Yasaka, "Measurement of 124-GHz E/O modulation bandwidth in hybrid modulation laser," IEEE Photonics Technology Letters, vol. 35, No. 10, pp. 565-568, 2023.

Advanced Wireless Information Technology

For realization of the next generation wireless devices and systems

Advanced Wireless Information Technology Noriharu Suematsu, Professor

[Research Target and Activities]

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

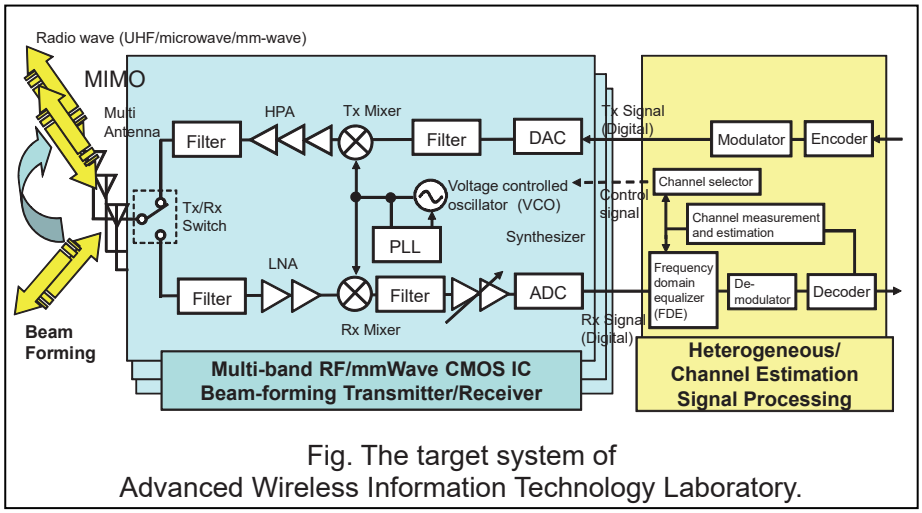


Fig. The target system of
Advanced Wireless Information Technology Laboratory.

This year, we have successfully developed a 40GHz direct digital RF transmitter which utilizing the 2nd. image component of 32Gbps NRZ DAC output. We also developed over 100GHz-band on-chip antenna measurement system.

[Staff]

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

[Profile]

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

[Papers]

[1] R. Tamura, M. Motoyoshi, S. Kameda, N. Suematsu, "7.5 GHz-Band Digital Beamforming Using 1-bit Direct Digital RF Transmitter with 10GbE Optical Module," 51th European Microwave Conference (EuMC), pp. 51-54, Apr. 2022.
[2] L. Zhu, S.-H. Shin, R. Payapulli, T. Machii, M. Motoyoshi, N. Suematsu, N. M. Ridler, S. Lucyszyn, "3-D printed sub-THz rectangular waveguide with integrated 65 nm CMOS RFIC," IEEE Microwave and Wireless Technology Letters (MWTL), Vol. 33, pp. 157-160, Feb. 2023.
[3] J. Zhang, N. Suematsu, "A 20GHz-Band Optical-Fiber-Feed 1-Bit Bandpass Delta-Sigma Direct Digital RF Transmitter Using First Image Component of the QSFP28 Module Output," 3rd URSI Atlantic and Asia Pacific Radio Science Meeting (AT-AP-RASC), May. 2022.
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[5] J. Zhang, N. Suematsu, "40GHz-Band Direct Digital RF Modulator using the 2nd Image Component of 1-Bit Delta-Sigma Modulated Signal," 2022 Asia-Pacific Microwave Conference (APMC), pp. 496-498, Nov. 2022.

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Information Storage System Laboratory

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

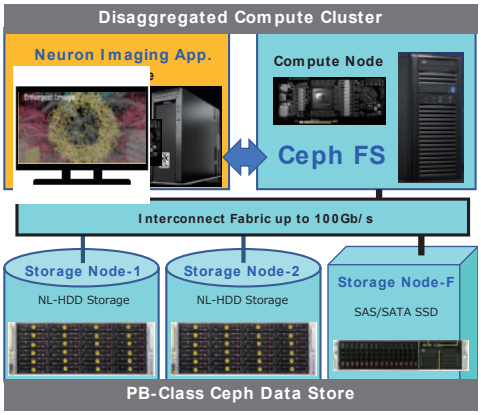
Information Storage・Computing Systems, Yoichiro Tanaka, Professor
Recording Theory Computation, Simon Greaves, Associate Professor

[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.

To increase the storage density and reduce the cost of data storage we are investigating novel, three-dimensional, energy-assisted recording technologies that enable selective recording on media with multiple, discrete recording layers [1][2]. This year, our research concentrated on heat-assisted magnetic recording (HAMR), with the aim of doubling the storage capacity. We have also been studying arrays of spintronic devices for use in artificial neural networks.

In addition, we have constructed a computational storage testbed system with 2PB storage with unified computation capability and integrated object based distributed storage Ceph. By using visualization analytics of brain neuro structures, large scale data access performance was evaluated.



Computational Storage Testbed

[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 and IEEE Magnetic Society Distinguished Lecturer for 2023.

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

[Papers]

[1] H. Yamane, S. Greaves and Y. Tanaka, "Optimising the thickness and diameter of dual structure patterned media dots for heat assisted magnetic recording", IEEE Trans. Mag. Vol. 58, No. 8, 3200705, (2022).
[2] S. J. Greaves and Y. Kanai, "Hysteresis loops of recording media grains under the influence of high-frequency fields", IEEE Trans. Mag. Vol. 59, No. 3, 3200607, (2023).
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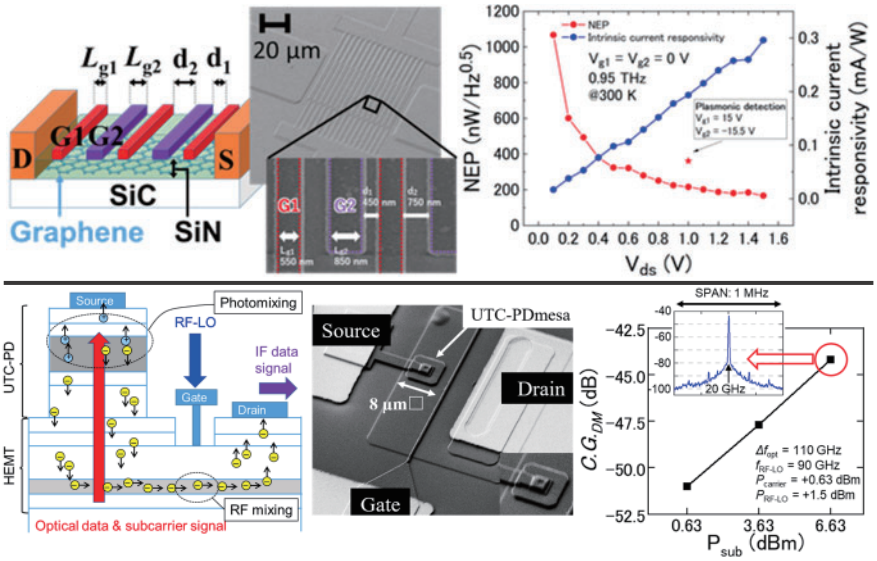
Ultra-broadband Signal Processing

Novel Millimeter-wave and Terahertz Integrated Electron Devices and Systems

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

[Research Target and Activities]



Top: Schematic and scanning-electron micrograph images of an asymmetric dual-grating gate graphene-channel FET THz detector (left) and measurement results of THz detection sensitivity (responsivity) and noise equivalent power (NEP) (right).

Bottom: Schematic scanning-electron micrograph images of the UTC-PD-integrated HEMT photonic double-mixer (left) and measurement results of the gain of 100-GHz optical-to-wireless carrier frequency down-conversion with high-intensity optical signal input (right).

We are developing novel, integrated electron devices and circuit systems operating in the terahertz (THz) region. First, a prototype field-effect transistor with a unique asymmetric double-grating gate structure using a monolayer of carbon atoms: graphene as a channel, and a new unipolar photothermoelectric terahertz detection mechanism involving only electrons was discovered, and high-speed, high-sensitivity terahertz wave detection was successfully achieved for the first time (press released on Dec. 2022). Second, regarding optical-to-wireless carrier frequency down-conversion devices (UTC-PD-integrated HEMT photonic double-mixers) required for realization of beyond-5G networks, we paid attention to a technique of generating low-noise, high-intensity optical signal input to a double-mixer and showed that the linear enhancement of the conversion gain with up to 10-dB enhancement is expected (received the Best Poster Paper Award at a prestigious international conference).

[Staff]

Professor: Taiichi OTSUJI, Dr. Eng.
Associate Professors: Akira SATOU, Dr. Comp. Sci.
Specially Appointed Associate Professor: Tsung-Tse LIN, Dr. Eng.
Assistant Professors: Takayuki WATANABE, Dr. Eng., and Chao TANG, Dr. Eng.
Research Fellow: Victor RYZHII, Ph.D. Secretary: Minori KANNO

[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] K. Tamura, C. Tang, D. Ogiura, K. Suwa, H. Fukidome, Y. Takida, H. Minamide, T. Suemitsu, T. Otsuji, and A. Satou, "Fast and sensitive terahertz detection in a current-driven epitaxial-graphene asymmetric dual-grating-gate FET structure," APL Photonics, vol. 7, iss. 7, pp. 16101-1-10, Dec. 2022. DOI: 10.1063/5.0122305 (Featured article)

[4] V. Ryzhii, T. Otsuji, M. Ryzhii, V. Mitin, and M.S. Shur, "Resonant plasmonic terahertz detection in gated graphene p-i-n field-effect structures enabled by nonlinearity from Zener-Klein tunneling," Phys. Rev. Appl., vol. 18, no. 3, pp. 034022-1-12, Sept. 2022. DOI:10.1103/PhysRevApplied.18.034022

[5] M. Ryzhii, V. Ryzhii, T. Otsuji, V. Mitin, and M.S. Shur, "Coulomb drag and plasmonic effects in graphene field-effect transistors enable resonant terahertz detection," Appl. Phys. Lett., vol. 120, iss. 11, pp. 111102-1-6, March 2022. DOI: 10.1063/5.0087678

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Quantum-Optical Information Technology

Development of optoelectronic devices for quantum information and communication technology

Quantum-Optical Information Systems: Keiichi Edamatsu, Professor
Quantum-Optical Information Devices: Fumihiro Kaneda, Associate Professor

[Research Target and Activities]

Our goal is to develop quantum information devices and systems utilizing quantum interaction between photons and electrons in solids. In 2022, we have achieved (1) evaluation of error-disturbance uncertainty relation in Faraday measurement, (2) generation of spectrally factorable photon pairs via controlled quasi-phase-matched spontaneous parametric down-conversion, (3) development of ultra-low-loss, circuit photon memory (buffer), and (4) plasmon-enhanced single photon source coupled to an optical nanofiber.

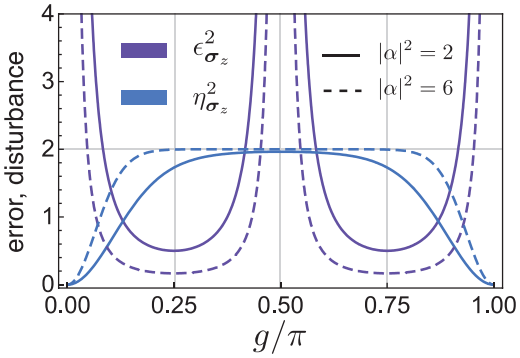

Fig. 1. Error-disturbance uncertainty relation in Faraday measurement.

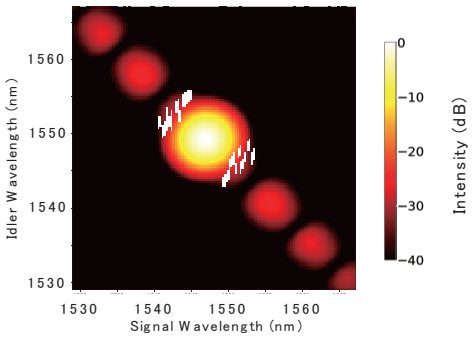

Fig. 2. Joint spectral distribution of a photon pair produced via controlled quasi-phase-matched spontaneous parametric downconversion.

[Staff]

Professor: Keiichi Edamatsu, Dr.
Associate Professor: Fumihiro Kaneda, Dr.
Assistant Professor: BAEK Soyoung, 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.

Fumihiro Kaneda received B.S. degree in Physics, M.S. and D.S. degrees in Engineering from Tohoku University. He was a Postdoctoral Research Fellow in University of Illinois, and an Assistant Professor in Frontier Research Institute for Interdisciplinary Sciences, Tohoku University.

[Papers]

[1] B.H. Le and K. Edamatsu, "Error-disturbance uncertainty relations in Faraday measurements", Phys. Rev. A 105, 052228 (2022) doi: 10.1103/physreva.105.052228
[2] M. Sugawara, Y. Xuan, Y. Mitsumori, K. Edamatsu, and M. Sadgrove, "Plasmon-enhanced polarized single photon source directly coupled to an optical fiber", Phys. Rev. Research 4, 043146 (2022) doi: 10.1103/physrevresearch.4.043146

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 beings as well as to establish communications environments in which humans 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 research 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 2022 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) We have developed a new synchronization method for high-frequency magnetic field measurements using a pulsed laser and a magnetic garnet. This research has made it possible to observe high-frequency magnetic field distributions. We also improved the performance of magnetic garnet materials to develop new magneto-optical devices, which may lead to the creation of devices that interact with living organisms and improve the detection of unwanted electromagnetic waves.

(2) Advanced Acoustic Information Systems

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

(Achievements) We have focused on the mechanism of auditory and multisensory information processing. To generate multimodal contents, we proposed a multiple regression model to decide the optimal amplitude of whole-body vibration using visual and acoustic features. We also investigated the usefulness of the presentation of spatio-temporal cues for speech comprehension in the cocktail party situation in patients with listening difficulties. In addition, we developed advanced acoustic systems, such as 3D virtual auditory displays, sound acquisition, and presentation systems. This

fiscal year, we proposed a new ear-centering method to synthesize near-field head-related transfer functions (HRTFs) from far-field HRTFs using the spherical Fourier transform and distance-varying filters.

(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) In 2022, our major achievements were the followings. 1) We investigated the method to estimate attentional levels during learning using facial expressions. We defined the attentional state as the response time to detect a target irrelevant to learning and attempted to predict the response time from facial expressions using a machine learning method. 2) Regarding collinear search impairment (CSI) in visual search, we examined the effect of grouping as a possible factor underlying the phenomenon. We examined whether the vertical grouping of elements of non-conspicuous lines influences the CSI, reducing the grouping effect with 45°orientation elements. The results showed that the grouping factor is not the cause of the CSI.

(4) Information Content

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

(Achievements) In this year, we primarily worked on a gaze-tracking system using a single smartphone, a magnetic-based force input interface for smartphone, a dead angle free magnetic 3D motion tracking system using monofrequency multiaxis 3D passive magnetic markers, and a room-scale interactive partitioning system using robotic partitions.

(5) Real-world computing

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

(Achievements) The main contributions achieved in 2022 are summarized as follows: (1) we have proposed an inter-limb coordination mechanism of centipedes that exploits flexible bodies; (2) we have proposed a mechanism for non-steady locomotion of extinct animals; (3) we have proposed a decentralized control scheme for mobile agents that can avoid collisions; (4) we have designed a quadruped robot that has flexible body based on anatomical findings.

(6) Nano-Bio Hybrid Molecular Devices

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

(Achievements) This year, we constructed two types of artificial cell membrane systems for functional analysis of ion channel proteins and established the technology basis for novel drug screening systems and innovative analysis of membrane protein functions. We also developed a surface modification method for recording the activity of patterned cultured neurons with high temporal resolution, and succeeded in pattern classification of speech signals using the stimulus responses of cultured neuronal networks. In addition, we have established a fabrication process of flexible electrodes for in vivo nerve stimulation based on bionanofiber films through an international collaboration.

(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 cross-cultural survey about the difference of gustatory evoked color-images with auditory evoked color-images; the role of the odor in transmittion of emotion; the evaluative change after receiving the information of the product. We have also started the cognitive studies about the development of the consciousness of vision and of audition, the attentional system of vision with audition.

Electromagnetic Bioinformation Engineering

Communication with human body

Electromagnetic Bioinformation Engineering, Kazushi Ishiyama, Professor
Electromagnetic Bioinformation Materials, Taichi Goto, Associate Professor

[Research Target and Activities]

This laboratory developed a new synchronization method for measuring high-frequency magnetic fields using a pulse laser and magnetic garnet. They also improved the performance of magnetic garnet materials to develop new magnetooptical devices, potentially leading to the creation of devices that interact with living organisms and improve detection of unwanted electromagnetic waves.

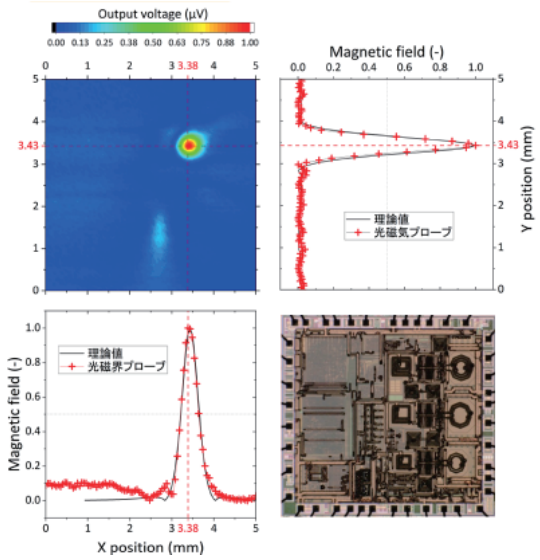

Fig. 1. Measurement results of the high-frequency magnetic field distribution generated by the microcoil inside the chip. The measured magnetic field frequency is 2.4 GHz.

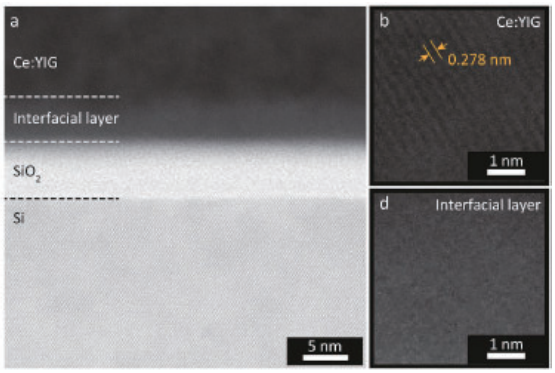

Fig. 2. Cross-sectional transmission electron microscope image of a cerium-doped magnetic garnet. Crystalline and non-crystalline areas have been identified.

[Staff]

Professor: Kazushi Ishiyama, Dr.
Associate Professor: Taichi Goto, Dr.

[Profile]

Kazushi Ishiyama received his MS and PhD degrees in Electrical Engineering from Tohoku University in 1986 and 1993, respectively. His research interests are magnetics and magnetic applications.
Taichi Goto received his MS and PhD degrees in Electronic Information Engineering from Toyohashi University of Technology in 2009 and 2011, respectively. His research interests are magnetics device and materials.

[Papers]

[1] Yuki Yoshihara, Tomoya Sugita, Pang Boey Lim, Yasuyuki Tamba, Hiroaki Inoue, Kazushi Ishiyama, Mitsuteru Inoue, Caroline A. Ross and Taichi Goto, "Thickness-dependent magnetooptical properties of ion beam sputtered polycrystalline $Ce_1Y_2Fe_5O_{12}$ films", Optical Materials, 133, 112967 (2022), doi: 10.1016/j.optmat.2022.112967.
[2] Hideyuki Horie, Takashi Isoyama and Kazushi Ishiyama, "Design of an Innovative Wireless Left Ventricular Assist Device Driven by either Extracorporeal Magnets or an Intracorporeal Battery Pack", ASAIO Journal, 69, e73-e79 (2023), 10.1097/mat.0000000000001874.

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.

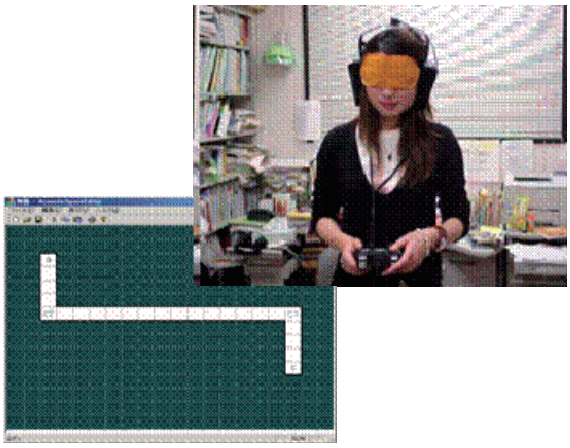

Fig. 1 Application for the training of spatial cognition using a high-definition virtual auditory display

In FY2022, we focused on the effectiveness of adding whole-body vibration information to audio-visual content. It is known that whole-body vibration, which vibrates the entire body, is closely related to perceived reality. We have reported that a low-pass filtered sound was regarded as a time wave of the vibration and provided to the users. This year, we investigated the vibration level perceived as optimal for the audio-visual content. The results of the experiments revealed that the optimal vibration level can be explained by a multiple regression model using acoustic and visual features of the audio-visual contents [1]. This result suggests that the optimal vibration level can be estimated for any type of content by extracting the acoustic and visual features.

[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] S. Abe, S. Sakamoto, Z. Cui, and Y. Suzuki, “Determination of optimal levels of whole-body vibration using audio-visual information of multimodal content,” Journal of Information Hiding and Multimedia Signal Processing, 13(4), 226-238(2022).
[2] T. Kawase, R. Teraoka, C. Obuchi, and S. Sakamoto, “Temporal and directional cue effects on the cocktail party problem for patients with listening difficulties without clinical hearing loss,” Ear and Hearing, 43(6), 1740-1751 (2022).
[3] A. Urviola, S. Sakamoto, and C. D. Salvador, “Ear centering for accurate synthesis of near-field head-related transfer functions” Applied Sciences, 12(16), 8290 (2022).

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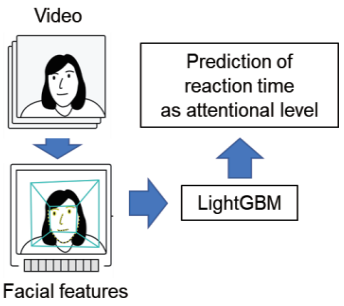
Visual Cognition and Systems Laboratory

Understanding human visual system for the better communication with visual information

Visual Cognition and Systems: Satoshi SHIOIRI, Professor
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. In 2022, our major achievements were the followings. 1) We investigated the method to estimate attentional levels during learning using facial expressions. We defined the attentional state as the response time to detect a target irrelevant sound and attempted to predict the response time from facial expressions using a machine learning method. 2) Regarding collinear search impairment (CSI) in visual search, we examined the effect of grouping as a possible factor underlying the phenomenon. We examined whether vertical grouping of elements of non-conspicuous lines influences the CSI, reducing the grouping effect with 45° orientation elements. The results showed that the grouping factor is not the cause of the CSI.



The schematic diagram of the proposed method. Attentional state is predicted from the facial features.

[Staff]

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

[Profile]

Satoshi SHIOIRI: Professor Shioiri graduated Tokyo Institute of Technology and received Dr. Eng in 1986. Then, he was a postdoctoral researcher at University of Montreal until 1989. From 1989 to 1990, he was a research fellow at Auditory and Visual Perception Laboratories of Advanced Telecommunications Research Institute. From 1990 to 2005, he was an assistant professor at Department of Image Sciences, an associate professor at Department of Image, Information Sciences, and a professor at Department of Medical Systems. Since 2005, he has been a professor at Tohoku University.
Chia-huei TSENG: 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. Before joining Tohoku University as associate professor in 2016, she was a university professor in Taiwan and Hong Kong.

[Papers]

[1] R. Miao, H. Kato, Y. Hatori, Y. Sato, S. Shioiri, “Analysis of Facial Expressions for the Estimation of Concentration on Online Lectures,” Proceedings of World Conference of Computers in Education, 2022.
[2] H. Kato, K. Takahashi, Y. Hatori, Y. Sato, S. Shioiri, “Prediction of Engagement from Facial Expression: Effect of Dynamic Factors,” Proceeding of the 18th International Conference on Intelligent Information Hiding and Multimedia Signal Processing, 2022.
[3] L Jingling, S Shioiri, Testing the effect of display organization in the collinear search impairment, Perception 51 (9), 658-671, 2022

Information Content

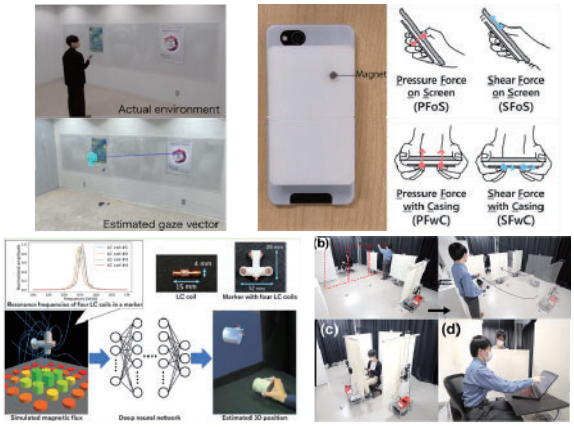
Technologies for Interactive Content

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

[Research Target and Activities]

As 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.

In this year, we primarily worked on a gaze-tracking system using single smartphone, a magnetic-based force input interface for smartphone, a dead angle free magnetic 3D motion tracking system, and a room-scale interactive partitioning system using robotic partitions.



[Staff]

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

[Profile]

Yoshifumi Kitamura: He is active in academic and professional communities, and has served in positions such as the Japan Liaison of IFIP TC-13 (Human-Computer Interaction), Japan Liaison and Chair of ACM SIGCHI Asian Development Committee, Chair of Japan ACM SIGCHI Chapter, Steering Committee Chair of ACM VRST, SIGGRAPH Asia 2015 Conference Chair, General Chair of ACM CHI 2021. 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. 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. Takahiro Nagai, Kazuyuki Fujita, Kazuki Takashima, Yoshifumi Kitamura, HandyGaze: A Gaze Tracking Technique for Room-Scale Environments using a Single Smartphone, Proc. of the ACM on Human-Computer Interaction, Vol. 6, ISS, 562, 143-160, November 2022.
2. Taichi Tsuchida, Kazuyuki Fujita, Kaori Ikematsu, Sayan Sarcar, Kazuki Takashima, Yoshifumi Kitamura, TetraForce: A Magnetic-Based Interface Enabling Pressure Force and Shear Force Input Applied to Front and Back of a Smartphone, Proc. of the ACM on Human-Computer Interaction, Vol. 6, ISS, 564, 185-206, November 2022,
3. Yuhei Osaka, Jiawei Huang, Yoshifumi Kitamura, Learning to Track Monofrequency Multiaxis 3-D Passive Magnetic Markers, IEEE Sensors Journal, 22, 19, 18878 - 18889, October 2022.
4. Yuki Onishi, Kazuki Takashima, Kazuyuki Fujita, Yoshifumi Kitamura, WaddleWalls: Room-scale Interactive Partitioning System using a Swarm of Robotic Partitions, Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology, 29, 1-15, October 2022.

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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.

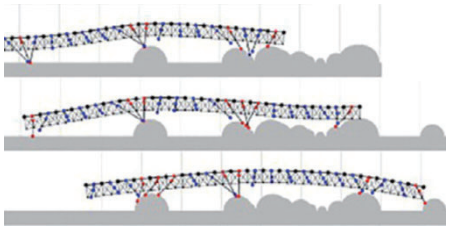


Fig.1: Adaptive centipede walking via synergetic coupling between decentralized control and flexible body dynamics

Fig.2: Decentralized control of multiple mobile agents for quick, smooth, and safe movement

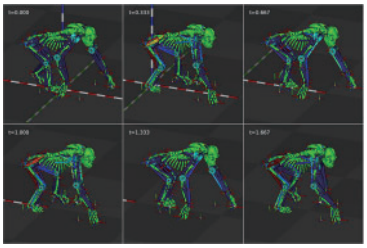


Fig.3: Autonomous decentralized gait control law for non-stationary motion

[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] Yasui K, Takano S, Kano T, Ishiguro A (2022) Adaptive centipede walking via synergetic coupling between decentralized control and flexible body dynamics. Front. Robot. AI, 9:797566.
[2] Kano T, Kanno T, Mikami T and Ishiguro A (2022) Active-sensing-based decentralized control of autonomous mobile agents for quick and smooth collision avoidance. Front. Robot. AI 9:992716.
[3] Sellers WI, Cross CF, Fukuhara A, Ishiguro A and Hirasaki E (2022) Producing non-steady-state gaits (starting, stopping, and turning) in a biologically realistic quadrupedal simulation. Front. Ecol. Evol. 10:954838.

Nano-Bio Hybrid Molecular Devices

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

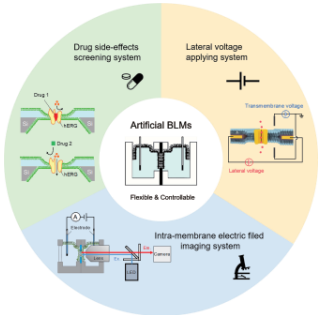
Nano-Bio Hybrid Molecular Devices: Ayumi Hirano-Iwata, Professor

[Research Target and Activities]

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

1. New aspects in artificial cell membrane systems for ion channel functional analysis

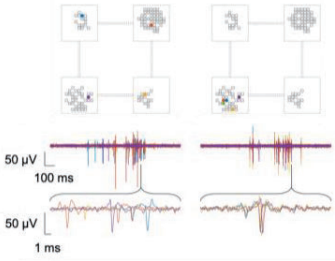
We have constructed two types of artificial cell membrane systems with different aspects. One is a cell membrane mimicry system combined with cell-free protein synthesis technology for the evaluation of drug side effects. The other is a four-terminal artificial cell membrane system that introduces a new input, parallel membrane voltage, in addition to the conventional transmembrane voltage. The details of our artificial cell membrane systems and their prospects are discussed. [Membranes, **12**, 863 (2022)]



Constructed artificial cell membrane systems

2. High spatiotemporal-resolution recording and biocomputing applications of artificial neuronal networks

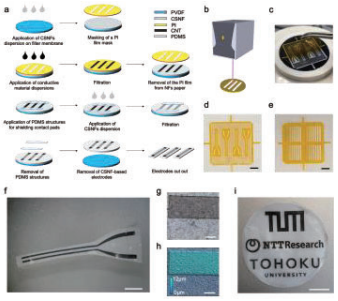
We established a new surface modification protocol for patterning cultured neurons on high-density multielectrode array (HD-MEA) devices and reconstituted neuronal networks with a modular structure. Measurement of spontaneous neural activity revealed that a fast, sub-millisecond activity propagation within modules could be captured in the HD-MEA recordings [Frontiers in Neuroscience 16, 943310 (2023)]. Furthermore, by using the framework of reservoir computing, the stimulus responses of cultured neural networks were decoded to realize pattern classification, revealing the relationship between network modularity and information processing performance.



Neuronal activities recorded with HD-MEA

3. Bionanofiber-based flexible electrodes for nerve stimulation

A flexible electrode was fabricated by combining chitosan nanofibers (CSNFs) and carbon nanotubes. The fabricated electrodes were used to stimulate the peripheral nerves of live locusts. This result was achieved through an international collaboration with Technical University of Munich. [J. Nanobiotechnol., **20**, 491 (2022)]



Fabrication of CSNF-based electrodes

[Staff]

Professor: Ayumi Hirano-Iwata, Dr.
Assistant Professor: Daisuke Tadaki, Dr.
Assistant Professor: Maki Komiya, Dr.
Assistant Professor: Kaoru Hiramoto, Dr.

[Profile]

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

[Papers]

[1] H. Kageyama, T. Ma, M. Sato, M. Komiya, D. Tadaki, A. Hirano-Iwata, "New aspects of bilayer lipid membranes for the analysis of ion channel functions". Membranes, **12**, 863 (2022).
[2] Y. Sato, H. Yamamoto, H. Kato, T. Tanii, S. Sato, A. Hirano-Iwata, "Microfluidic cell engineering on high-density microelectrode arrays for assessing structure-function relationships in living neuronal networks", Front. Neurosci., **16**, 943310 (2023).
[3] D. Ando, T.F. Teshima, F. Zurita, H. Peng, K. Ogura, K. Kondo, L. Weiß, A. Hirano-Iwata, M. Becherer, J. Alexander, B. Wolfrum, "Filtration-processed biomass nanofiber electrodes for flexible bioelectronics", J. Nanobiotechnol., **20**, 491 (2022).

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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 six research fields related to such high-level ubiquitous systems, software and contents by integrating computer and communication:

— Computing Information Theory: Fundamental theory of new software.
— Communication Network: Network systems and applications.
— 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. 2022 to Mar. 2023 of these fields except the visitor section is described in this section.

(1) Computing Information Theory

Continuing on from last year, we have studied bidirectional transformation (BX) techniques applied to data synchronization and data sharing. One of this year's research results is a successful expressiveness comparison of some BX languages as a first step to organizing many existing BX languages. As a stepping stone to developing computational models of BX, which are indispensable for estimating expressive powers of BX languages, we have designed a time-symmetric Turing machine as a computational model for the congruence function, which is closely related to BX. In addition, we introduced a unified semantic framework of linear logic, which refines a state-of-the-art model of quantum programming languages. In parallel with them, we have proved that, in higher-order program verification, the order-n reachability problem is equivalent to the order-(n+1) May-reachability problem. Furthermore, as a theoretical foundation of software verification, we introduced the notion of strong commutation modulo alpha-equivalence in nominal rewriting systems defined by rewrite rules with atom variables, and used it to present a new condition for confluence on ground nominal terms.

(2) Communication Network Systems

We have promoted research on information network systems and their applications that support diverse human activities. In the study on remote management of network equipment using low-speed and long-life networks, we proposed a technology for efficiently compressing and transmitting commands for networking device operations using a communication method called LPWA, which has low speed but wider-area communication and consumes lower power, to remotely manage equipment that constitutes a large-scale network spanning remote locations. We showed that it can compress up to 95% of communication volume. In addition, in the study on internet congestion control, we proposed a new architecture that actively performs congestion control at network nodes rather than the conventional end-to-end congestion control, and revealed its potential through mathematical analysis. Furthermore, in the research on agent-type IoT and its applications, we prototyped and evaluated a mobile agent framework for small IoT devices.

(3) Environmentally Conscious Secure Information System

We are studying future secure information communication systems from theories to implementation technologies for constructing advanced information and communication infrastructures in a safe and secure manner. In this year, we developed novel hardware architectures to efficiently realize cryptographic hardware including those of post-quantum cryptography (PQC) that is resistant to quantum computers. In particular, we have developed a hardware architecture that can achieve the world's highest efficiency for Crystals-Kyber, which was standardized as PQC by the National Institute of Standards and Technology (NIST), and for AES, which is the most widely used international standard block cipher. We also developed a security evaluation technology based on a new design and evaluation platform in addition to new machine-learning-based analysis methods for physically secure implementation of cryptographic hardware. The developed technology makes it possible to perform security evaluation with the highest accuracy for software and hardware of international standard cryptography such as Crystals-Kyber and AES. It is also effective as a technique for estimating the cost of the optimal attack more accurately than ever.

(4) 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. (1) Discrete word speech recognition experiments were conducted using a chaotic neural network reserver (CNNR) LSI implemented in 3D stacking by Through Silicon Via and Micro Bump. Furthermore, we applied FORCE learning to CNNRs and successfully generated time series using CNNRs with various dynamics including hyperchaos. In addition, chaotic neurons were introduced in the output layer neurons to perform time series prediction, and very high performance was confirmed. (2) In order to refine the mathematical models of spin-orbit torque neuron-like and synapse-like devices based on thermal dynamics, we have modeled them using thermal circuits and analyzed them in detail using a physical simulator. (3) We proposed a neural network that introduces internal state time constants and self-coupling time constants as local memories in the reservoir neural network, and investigated speech recognition performance through simulation experiments. (4) In order to implement the spatio-temporal context learning and memory network as a spiking neuron circuit, we described it as a continuous-time differential equation model with a basic circuit configuration, and confirmed its effectiveness through circuit experiments.

(5) New Paradigm VLSI System

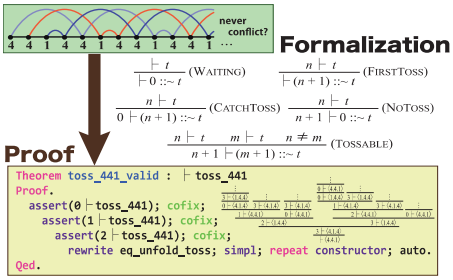
Our research activity is to solve the several limitations such as power dissipation, performance and reliability due to the present binary-CMOS-based VLSI computing. The key approach to breaking through such limitations is primarily the following two ways: the logic-in-memory architecture based on nonvolatile logic, and the brainware LSI (BLSI) computing, which would open up a novel VLSI chip paradigm, called a “new-paradigm VLSI system.” In FY 2022, we have preliminarily achieved the following two activities. (a) First, we have succeeded in realizing an energy-efficient CPU based on spintronics/CMOS-hybrid

technology. By incorporating a PG (power gating)-control instruction into a general-purpose CPU (RISC-V) instruction set, the overhead associated with PG control has been greatly reduced, achieving energy savings. Applied to the execution of a typical arithmetic circuit, significant power saving has been achieved (J. Mem.-Mat., Dev., Cir. & Sys., 2023; doi: 10.1016/j.memori.2023.100035). (b) In addition, FPGA-oriented hardware that solves combinatorial optimization problems at high speed based on stochastic computing, and succeeded in significantly improving performance compared to conventional methods (IEEE JETCAS, March 2023; doi: 10.1109/JETCAS.2023.3243260). This year's research results, including the above, were reported in 4 academic journal papers, 8 refereed international conference papers, and 1 book.

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.
Assistant Professor : Kentaro Kikuchi, Dr.

[Profile]

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

[Papers]

[1] Keisuke Nakano. Time-symmetric Turing machines for computable involutions, Science of Computer Programming, Volume 215, 102748.
[2] Takeshi Tsukada and Kazuyuki Asada. Linear-Algebraic Models of Linear Logic as Categories of Modules over Sigma-Semirings, In Proc. the 37th Annual ACM/IEEE Symposium on Logic in Computer Science (LICS 2022), No. 60, pp. 1-13, ACM
[3] Kentaro Kikuchi. Ground Confluence and Strong Commutation modulo Alpha-Equivalence in Nominal Rewriting, In Proc. of the 19th International Colloquium on Theoretical Aspects of Computing (ICTAC 2022), LNCS 13572, pp. 255-271, Springer.

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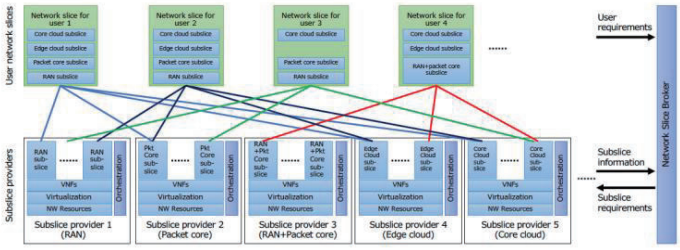
Communication Network Systems

Information Network Architecture for the IoT Society

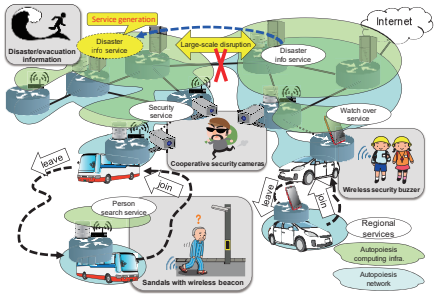
Information Network Architecture: Go Hasegawa, Professor

[Research Target and Activities]

In this year, the following studies had been done. (a) Research on Internet congestion control including in-Network Congestion Control architecture and Machine learning-based estimation of network environment and its application to congestion control, (b) Research on virtualized network systems and applications, including mobile core network architecture for 5G and beyond, User-Oriented Network Architecture (UONA), Mobile traffic prediction for network resource allocation, and analysis of edge-cloud networking systems, (c) Traffic compression technologies for LPWA-based remote network equipment operations, and (d) Mobile agent technologies for LPWA-based lightweight IoT terminals.



Network slicing architecture for beyond-5G networks.



An image of autopoietic networking.

[Staff]

Professor : Go Hasegawa, Dr.
Secretary : Ami Nagashima

[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.

[Papers]

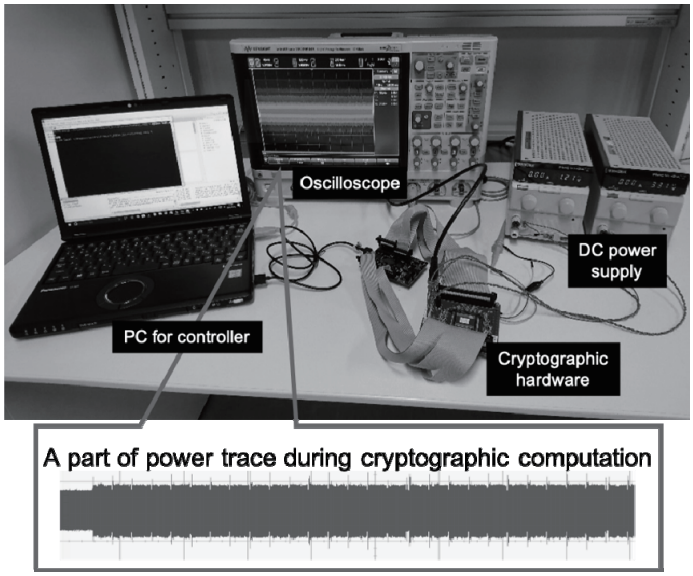
[1] Xun Shao, Go Hasegawa, Mianxiong Dong, Zhi Liu, Hiroshi Masui, Yusheng Ji, "An Online Orchestration Mechanism for General-Purpose Edge Computing," to appear in IEEE Transactions on Service Computing, 2022.Link
[2] Shuya Abe, Go Hasegawa, Masayuki Murata, "Performance Analysis of Mobile Cellular Networks Accommodating Cellular-IoT Communications with Immediate Release of Radio Resources," IEICE Transactions on Communications, Vol.E105-B, No.12, pp.1477-1486, Dec. 2022. Link
[3] Yukio Ogawa, Go Hasegawa, Masayuki Murata, "Probabilistic Control of Dynamic Crowds Toward Uniform Spatial-Temporal Coverage," IEEE Transactions on Mobile Computing, Dec 2022.
[4] Satoshi Utsumi and Go Hasegawa, "Improving Inter-Protocol Fairness Based on Estimated Behavior of Competing Flows," in Proceedings of IFIP Networking 2022 June 2022.Link
[5] Keito Maeta, Gen Kitagata and Go Hasegawa, "Improving Per-Flow Fairness by ML-Based Estimation of Competing Flows' Congestion Control Algorithm," in Proceedings of IEEE ICUFN 2022, July 2022.Link
[6] Ryu Yachikojima, Shin'ichi Arakawa, Takeshi Kitahara, Nagao Ogino, Go Hasegawa, and Masayuki Murata, "Low-latency Probabilistic Collision Detection Method for C-V2X Applications," in Proceedings of ICVTS 2022, September 2022.
[7] Kodai Tanabe, Go Hasegawa, and Gen Kitagata, "Traffic Reduction for Out-Of-Band Network Management over LPWA," in Proceedings of IEEE ICOIN 2023, January 2023.

Environmentally Conscious Secure Information System Laboratory

Advanced information security technology

Environmentally Conscious Secure Information System, Naofumi Homma, Professor

[Research Target and Activities]



We are studying future secure information communication systems from theories to implementation technologies for constructing advanced information and communication infrastructures in a safe and secure manner. In this year, we have discovered and reported some impelementation attacks on public key cryptosystems such as RSA and post-quantum cryptography (PQC), including Crystals–Kyber, which is a winner of NIST PQC standardization competition. We validated the attacks experimentally, have developed their countermeasure, and confirmed the effectiveness through further experiments. In addition, we have developed efficient hardware architectures for computing PQCs. Furthermore, we have provided in-depth analyses on side-channel attacks on cryptographic implementations from the viewpoints of probability and information theories. As a result, we succeeded in formally proving the security of side-channel attack countermeasure called masking under a much more relaxed and practical condition than a previous proof. Moreover, we pointed out an uncertainty of previous metrics for evaluating success rate of side-channel attacks, and then presented new metrics to revise it. We also showed that our metrics have some good properties in terms of statistics and practical computations.

[Staff]

Professor: Naofumi Homma, Ph. D
Assistant Professor: Rei Ueno, Ph. D
Secretary: Mikiko Hattori

[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] Kotaro Saito, Akira Ito, Rei Ueno, and Naofumi Homma, "One Truth Prevails: A Deep-learning Based Single-Trance Power Analysis on RSA--CRT with Windowed Exponentiation," *IACR Trans. Cryptogr. Hardw. Embedded Syst.*, 2022(4), pp.490–526, 2022.

[2] Akira Ito, Rei Ueno, and Naofumi Homma, "On the Success Rate of Side-Channel Attacks on Masked Implementations: Information-Theoretical Bounds and Their Practical Usage," *ACM CCS*, pp. 1521–1535, 2022.

[3] Akiko Inoue, Kazuhiko Minematsu, Maya Oda, Rei Ueno, and Naofumi Homma, "ELM: A Low-Latency and Scalable Memory Encryption Scheme," IEEE Trans. Inf. Forensics Security, 2022.

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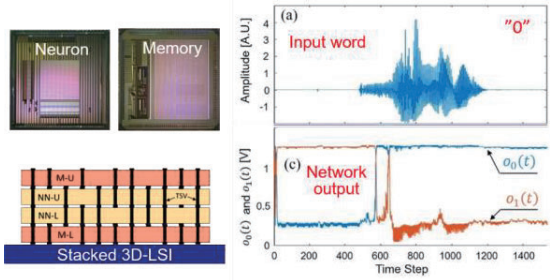
Soft Computing Integrated System

Brainmorphic Computing Hardware System

Soft Computing Integrated System Yoshihiko Horio, Professor

[Research Target and Activities]



We are working on a novel high-performance, highly-efficient, flexible, and robust "brainmorphic" computing hardware system through physical complex-networked dynamical process using novel nano-scale devices. Toward the final goal, we are developing integrated circuit and device technologies suitable for the brainmorphic computer systems, ultra-low-power asynchronous neural network systems, neuron-like and synapse-like spintronics devices, and a brainmorphic system architecture. During the FIY 2022; 1) We conducted discrete word speech recognition experiments using a chaotic neural network reservoir (CNNR) 3D-LSI. Furthermore, we successfully applied FORCE learning to CNNRs, and we newly introduced chaotic neurons in the output layer; 2) We improved neuron-like and synapse-like spintronics device models using thermal circuits; 3) We proposed a reservoir neural network that introduces an internal state time constant and a self-coupling time constant; and 4) We described the spatio-temporal learning and memory network as a continuous-time differential equation model.

[Staff]

Professor：Yoshihiko Horio, Ph.D.
Specially Appointed Researcher：Takemori Orima, Dr.（from October,2022）
Technical Assistant：Mariko Takahashi

[Profile]

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

[Papers]

[1] K. Onuki, K. Cho, Y. Horio, and T. Miyano, "Secret-key exchange through synchronization of randomized chaotic oscillators aided by logistic hash function," IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 69, no. 4, pp. 1655-1667, DOI: 10.1109/TCSI.2022.3140762, 2022.
[2] T. Orima and Y. Horio, "Preliminary experimental results of a stacked 3D cyclic chaotic neural network reservoir integrated circuit," NOLTA, IEICE, vol. 13, no. 2, pp. 306-311, DOI: 10.1587/nolta.13.306, .2022.
[3] Y. Horio, K. Naoe, S. Sato, Y. Yamanouchi, Y. Takaura, M. Yamaguchi, M. Morishima, and A. Hirano-Iwata, "Designing the human-centric IoT society: Cooperative industry-academic strategies for creative future connection," NOLTA, IEICE, vol. 13, no. 2, pp. 197-202, DOI: 10.1587/nolta.13.197, 2022.

New Paradigm VLSI System Research Group

Realization of a New-Paradigm VLSI-Computing World

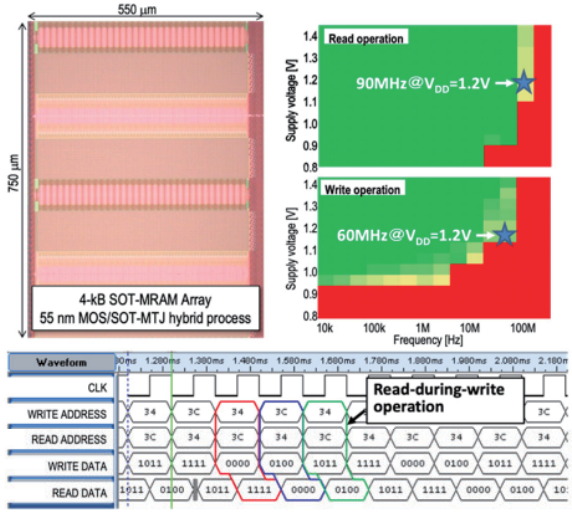


Fig. 1. A dual-port nonvolatile memory using 3-terminal spintronics devices (SOT-MRAM) achieving high-speed read / write / read-during-write operations

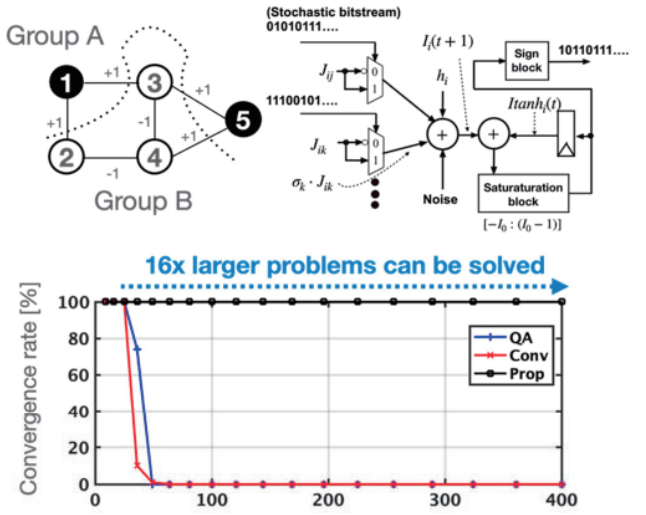


Fig. 2. Proposed simulated-annealing method can solve 16x larger combinational optimization problems than the quantum annealing machine, D-wave.

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

[Research Target and Activities]

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

This year, we have succeeded to design the nonvolatile-register-embedded energy-efficient CPU for IoT application (Fig. 1), and the fast-converging stochastic simulated annealing for solving large-scale combinational optimization problems based on FPGA (Fig. 2).

[Staff]

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

[Profile]

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

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

[Papers]

[1] N. Onizawa, et al., "Fast-Converging Simulated Annealing for Ising Models Based on Integral Stochastic Computing," IEEE Trans. on Neural Networks and Learning Systems, 2023 (in press).
[2] D. Shin, et al., "Memory-Efficient FPGA Implementation of Stochastic Simulated Annealing," IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 13, no. 1, pp. 108-118, Mar. 2023.
[3] M. Natsui, K. Sakamoto, and T. Hanyu, "Design of a Nonvolatile-Register-Embedded RISC-V CPU with Software-Controlled Data-Retention and Hardware-Acceleration Functions," Memories - Materials, Devices, Circuits and Systems, vol.4, pp.100035-1-100035-9, 2023.
[4] D. Suzuki and T. Hanyu, "Design of an Energy-Efficient Nonvolatile Lookup Table Circuit Using Active-Load-Localized Circuitry with Self-Terminated Writing/Reading," Japanese Journal of Applied Physics (JJAP), 2023 (in press).

In addition to the above achievements, there are 6 refereed international conference papers in FY 2022.

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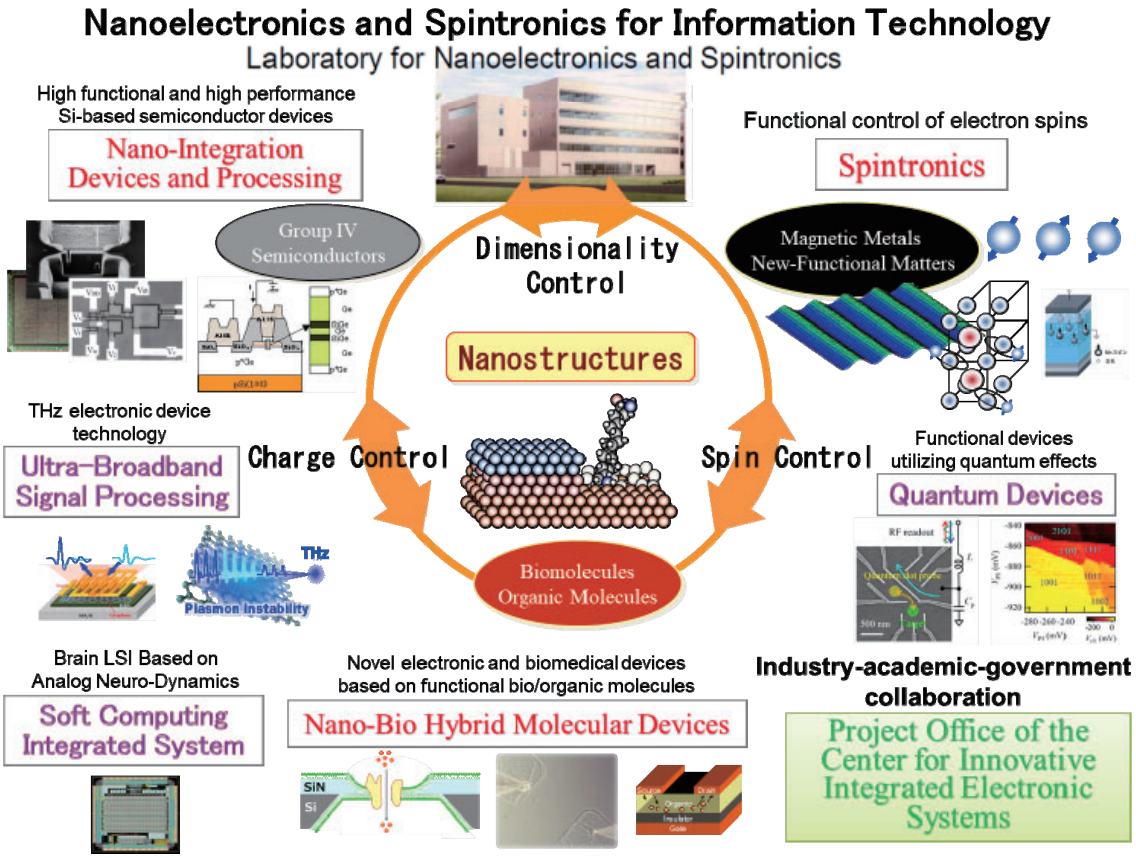
Laboratory for Nanoelectronics and Spintronics

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 2022 are shown below.

Nano Integration

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

(1) A spiking neuron that reproduces various neural pulses and operates at extremely low power was implemented on an LSI, and a recurrent neural network was constructed using it and applied to reservoir computing. It has been confirmed by electrical measurements that time-series signals such as speech signal could be correctly classified.

(2) To develop high-voltage and low-loss power semiconductor devices, double ion-implanted Al-gate 4H-SiC MOS transistors were fabricated utilizing high-temperature wet oxidation, and clear transistor-operation characteristics with low gate leakage were demonstrated even for gate length of 5 micron.

(3) We developed defined neuronal networks with a modular design on high-density microelectrode arrays (HD-MEAs), using a surface coating protocol involving a cell-permissive hydrogel for secure attachment of a polydimethylsiloxane microfluidic film. The spontaneous neural activity recorded from these engineered networks demonstrated that the modular architecture enhances functional complexity by reducing excessive neural correlation between spatially separated modules.

(4) A method for reservoir computing using Josephson transmission lines has been proposed. Numerical experiments show that fast and low-power time series recognition is possible using the Josephson junctions.

● Soft Computing Integrated System (Y. Horio)

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

(1) Discrete word speech recognition experiments were conducted using a chaotic neural network reserver (CNNR) LSI implemented in 3D stacking by Through Silicon Via and Micro Bump. Furthermore, we applied FORCE learning to CNNRs and successfully generated time series using CNNRs with various dynamics including hyperchaos. In addition, chaotic neurons were introduced in the output layer neurons to perform time series prediction, and very high performance was confirmed.

(2) In order to refine the mathematical models of spin-orbit torque neuron-like and synapse-like devices based on thermal dynamics, we have modeled them using thermal circuits and analyzed them in detail using a physical simulator.

(3) We proposed a neural network that introduces internal state time constants and self-coupling time constants as local memories in the reservoir neural network, and investigated speech recognition performance through simulation experiments.

(4) In order to implement the spatio-temporal context learning and memory network as a spiking neuron circuit, we described it as a continuous-time differential equation model with a basic circuit configuration, and confirmed its effectiveness through circuit experiments.

Spintronics and Information Technology

● Spintronics (S. Fukami and S. Kanai)

Our research activities focus on realizing low-power functional spintronic devices. The outcomes in the last fiscal year are as follows: (1) discovering the generalized scaling law describing the phase coherence time of quantum information in solids, (2) proposing a new principle of inductance that arises from magnetization dynamics caused by the spin-orbit interactions, (3) observing the magnetic domain structure of noncollinear antiferromagnetic Mn_3Sn thin film and clarifying the relation with the transport properties, (4) experimentally determining the unrevealed factor in the mathematical expression of the thermally-activated magnetization reversal under magnetic fields and electric current, (5) quantifying the spin-orbit torque in FeRh/NiFe heterostructure and revealing unexpectedly large spin-orbit torque arising when FeRh is in the antiferromagnetic phase, (6) proposing and demonstrating the external field robust stochastic magnetic tunnel junction utilizing synthetic antiferromagnetic coupling, (7) demonstrating the high computation performance and low power capability using a system with stochastic magnetic tunnel junction and field-programmable-gate-array, (8) summarizing the new paradigm of antiferromagnetic spintronics which is characterized by the coherent dynamics of collective antiferromagnetic spin structures, (9) quantifying the thermal stability factor of noncollinear antiferromagnetic Mn_3Sn nanodots with single domain structure, and (10) measuring the non-linear transport properties of nanoscale magnetic tunnel junction with perpendicular magnetic anisotropy and discussing their origin.

● 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 this fiscal year.

1. Development of graphene-channel terahertz detectors

Graphene, a monolayer sheet of honeycomb carbon crystal, is expected to break through the limit on conventional device operating speed/frequency performances. In this fiscal year, we developed a graphene-channel field-effect transistor with our original asymmetric dual-grating gates, discovered a novel unipolar photothermoelectric terahertz detection mechanism that only electrons contribute, and demonstrated its fast response time and high responsivity for the first time. (Press-released on December 2022)

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 have developed photonic double-mixers based on InGaAs-channel high-electron-mobility transistors. In this fiscal year, we paid attention to a technique of generating low-noise,

high-intensity optical signal input to a double-mixer and showed that the linear enhancement of the conversion gain with up to 10-dB enhancement is expected. (Received the Best Poster Paper Award at a prestigious international conference)

● **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 2022 are the following.

(1) We developed electronic measurement and control methods of local electronic states in nanostructures utilizing semiconductor quantum dots. We improved the methods with high-frequency techniques and applied them to new materials.

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

(3) We studied semiconductor quantum bits for future quantum information processing. We worked on state analysis and control of quantum devices to scale up the systems and new material-based devices.

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 have constructed two types of artificial cell membrane systems with different aspects. One is a cell membrane mimicry system combined with cell-free protein synthesis technology for the evaluation of drug side effects. The other is a four-terminal artificial cell membrane system that introduces a new input, parallel membrane voltage, in addition to the conventional transmembrane voltage. The details of our artificial cell membrane systems and their prospects are discussed.

(2) We established a new surface modification protocol for patterning cultured neurons on high-density multielectrode array (HD-MEA) devices and reconstituted neuronal networks with a modular structure. Measurement of spontaneous neural activity revealed that a fast, sub-millisecond activity propagation within modules could be captured in the HD-MEA recordings. Furthermore, by using the framework of reservoir computing, the stimulus responses of cultured neural networks were decoded to realize pattern classification, revealing the relationship between network modularity and information processing performance.

(3) A flexible electrode was fabricated by combining chitosan nanofibers (CSNFs) and carbon nanotubes. The fabricated electrodes were used to stimulate the peripheral nerves of live locusts. This result was achieved through an international collaboration with Technical University of Munich.

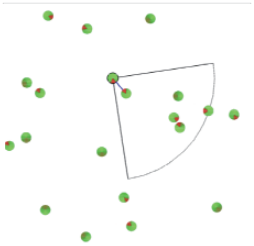
Research Targets and Activities of Laboratory for Brainware Systems

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.

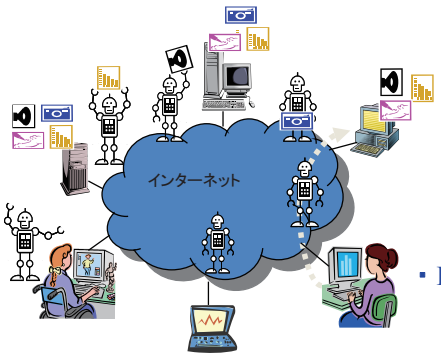
The technology developed in the Laboratory is expected to enhance the research carried out in the four Divisions of the Institute, and the research conducted in the Divisions, in turn, is expected to provide scientific basis for the information technology developed in the Laboratory.

Physical and Adaptive Hardware Environment

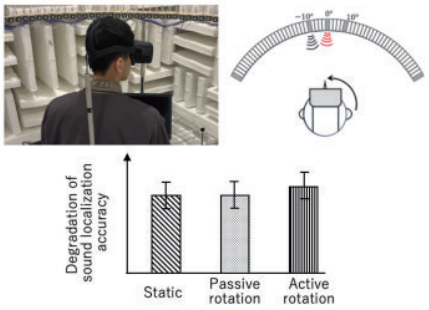


・Brain-Like Computing

(Brain Architecture)



Seamless Fusion of Real World and Multi-Modal Computing

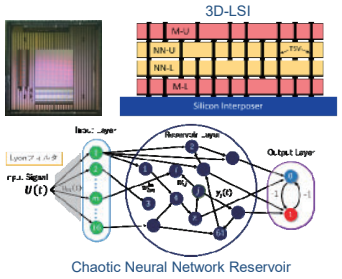


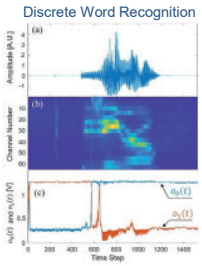
Auditory space perception during self-rotation

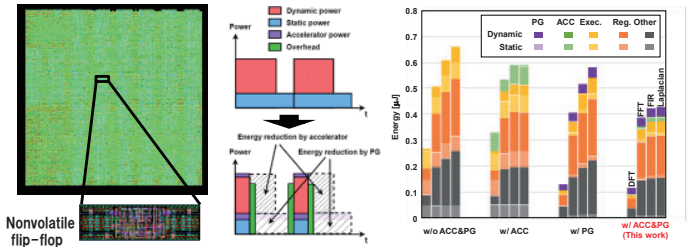
・Higher-Order Multimodal Perception and Information Generation

(Recognition and Learning Systems)

Hardware Environment with Massively Parallel Brain LSI







・Low-Power Nonvolatile CPU for IoT Edge Devices

(New Paradigm VLSI System)

[Research Target]

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

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

function like animals by implementing the obtained design principle.

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

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

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

[Research Activities]

Aiming at the seamless integration of the cyber-physical world and the real world, which is the goal of Laboratory of Brainware Systems, the following research results were obtained. In particular, the following research results in fiscal year 2022 are an important step towards the goal as:

--Real-World Computing Section demonstrates "Active-sensing-based decentralized control of autonomous mobile agents for quick and smooth collision avoidance" reported in Frontiers in Robotics and AI.
https://www.frontiersin.org/articles/10.3389/frobt.2022.992716/full

--New Paradigm VLSI System Section has succeeded in inserting a PG (power gating) control instruction into the original instruction set of a nonvolatile CPU (RISC-V), and in significantly reducing power dissipation during typical arithmetic operations such as FFT and Laplacian filtering.
https://www.sciencedirect.com/science/article/pii/S2773064623000129

--Recognition and Learning Systems Section reported "Prediction of Image Preferences from Spontaneous Facial Expressions" in Interdisciplinary Information Sciences (2022) Vol. 28 (1) pp. 45-53
https://www.jstage.jst.go.jp/article/iis/28/1/28_2022.A.02/_article

--Soft Computing Integrated System Section succeeded in speech recognition experiments with a chaotic neural network reservoir (CNNR) 3D LSI, application of FORCE learning to CNNR, and introduction of chaotic neurons in the output layer.
https://doi.org/10.1587/nolta.13.306

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 effects of hand movements on the hand proximity attention. Visual processing is facilitated around a hand, which is known as hand proximity attention. Visual probes were presented around a hand using a head mount display (HMD). The participant held a pen type force feedback device (Phantom omni) by a hand to move the device along a circular path. The pen tip was attached to a ball bearing so the pen movement was restricted to a circular path. While the participant was moving a hand or keeping it stationary, visual stimuli were presented at various locations along the circular path, with which attention effect was measured. The attention effect varied dependently on the distance from the hand, suggesting the hand proximity attention without a visual hand. The hand proximity effect is larger with a hand in motion comparing with a hand in stationary. Further analysis showed that attention modulation with active hand movement was not different from that with passive hand movement. The present experiment revealed that moving hand attracts attention more than stationary hand.

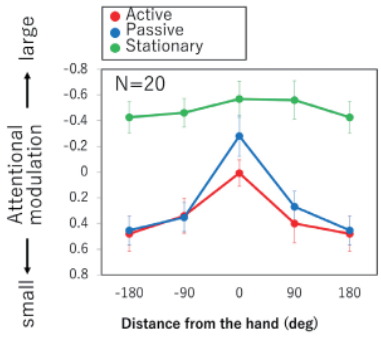


Figure. Comparison of attention modulation around a hand between hand movement and stationary conditions.

Second, we investigated the relationship between self-motion and auditory space perception. We have especially focused on sound localization accuracy during self-motion. The results of the experiment revealed that the sound-localization resolution degraded when the listeners are actually/virtually rotating. During perceptual information processing, the listener should constantly update sound image position information via conscious head/body movement, resulting in an increase in the amount of information to be processed. Therefore, the results suggest that a top-down process induced by listeners' conscious perception of motion may act as a constraint against such information processing overload.

[Staff]

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

[Papers]

[1] S Shioiri, K Iwai, CH Tseng, Y Hatori, Hand proximity attention with a moving hand, Journal of Vision 22 (14), 3482-3482, doi:https://doi.org/10.1167/jov.22.14.3482

[2] S Shioiri, K Iwai, CH Tseng, Y Hatori, The effect of perceived hand location on hand proximity attention, PERCEPTION 51, 30-31

[3] Y. Ssyo, Y. Hotsguchi, L. anel, S. Shioiri, Interdisciplinary Information Sciences (2022) Vol. 28 (1) pp. 45-53, https://www.jstage.jst.go.jp/article/iis/28/1/28_2022.A.02/_article/-char/ja/

[4] S. Honda, S. Tsunokake, Y. Suzuki, S. Sakamoto, Auditory subjective-straight-ahead blurs during significantly slow passive body rotation. *i-Perception* 13(1), 1-5 (2022).

[5] A. Honda, K. Maeda, S. Sakamoto, Y. Suzuki, Effects of visually nduced self-motion on sound localization accuracy, *Applied Sciences* 12(1), 173 (2022).

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 three projects, "Development of the education support system with estimation of attention states", "Drone utilization technologies to realize a symbiotic society" and "Wireless IoT technology for smart factories". 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, three governmental R&D projects are carried out in this group.

[Staff]

Director: Noriharu Suematsu, Professor

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

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

Interdisciplinary Collaboration Research Division

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

Challenging and Exploratory Research Division

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

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

Dependable Air

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

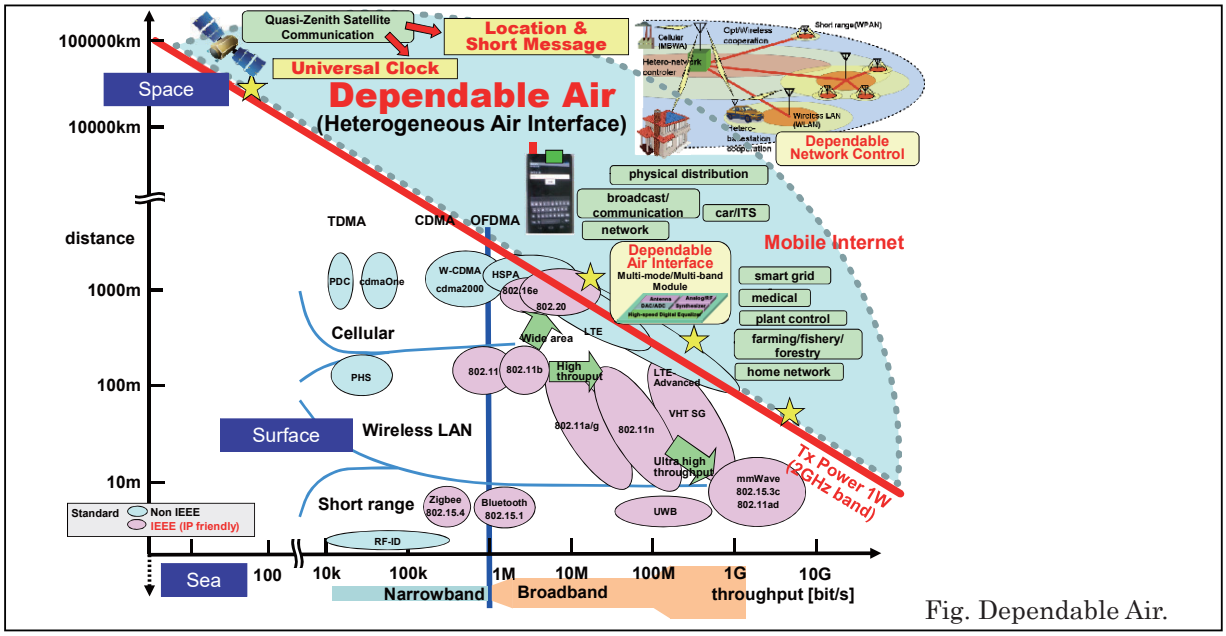


Fig. Dependable Air.

[Research Target and Activities]

Mobile wireless communication technology is one of the significant communication technologies that support the Information and Communication Technology (ICT) society, connected with the high-speed backbone network using optical fiber. Evolution of the mobile wireless communication technology in Japan is indispensable to keep the leadership in this technology area in the world. The mobile wireless technology group has been proposing the concept of "Dependable Air," which is a heterogeneous and highly-reliable wireless network. The Dependable Air is able to work even in the event of a big disaster. The group proceeded a R&D project "R&D on Technologies to Densely and Efficiently Utilize Radio Resources of Unlicensed Bands in Dedicated Areas" supported by the Ministry of Internal Affairs and Communications (MIC) from 2017. The group had also proceeded 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. From 2020, the group started sub-10GHz/28GHz Si RFICs for B5G station under the R&D project supported by NEDO. From 2022, the group start two R&D projects relating to spectrum monitoring and sensing of wireless IoT for smart factories under the R&D project supported by MIC.

[Staff]

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

[Papers]

[1] T. Shiba, T. Furuichi, K. Akimoto, M. Motoyoshi, S. Kameda, N. Suematsu, "Real-Time Wideband Spectrum Monitor Using Multiple Sampling Frequency Direct RF Undersampling for Wireless IoT," 2021 51th European Microwave Conference (EuMC), pp. 461-471, Apr. 2022.
[2] T. Furuichi, M. Motoyoshi, S. Kameda, T. Shiba, N. Suematsu, "RF Signal Frequency Identification in a Direct RF Undersampling Multi-band Real-time Spectrum Monitor for Wireless IoT Usage," IEICE Transactions on Communications, vol. E105-B, no. 4, Apr. 2022.
[3] T. Furuichi, K. Akimoto, M. Motoyoshi, S. Kameda, T. Shiba, N. Suematsu, "A Simple Spectrum Reconstruction Method in Direct RF Undersampling Receiver for Real-Time Spectrum Monitor," IEICE Transactions on Electronics, Vol.J105-C, no. 4, pp.117-126, Apr. 2022.
[4] T. Furuichi, T. Shiba, N. Suematsu, "Multi-band RF Spectrum Reconstruction from Multiple Direct RF Undersampled Signals," 2022 URSI-Japan Radio Science Meeting, Sep. 2022.
[5] Y. Fujiya, K. Edamatsu, T. Shiba, N. Suematsu, "Self-Mixing Noise Reduction Effect in Wi-Fi Backscatter Receiver by Tx Signal Canceller," 2022 IEEE Asia-Pacific Microwave Conference (APMC), pp. 493-495, Nov. 2022.

Interdisciplinary Collaboration Research Division

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

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

[Research Target and Activities]

In this year, we developed a method to experimentally investigate the process of integrating audiovisual information into binocular rivalry, and revealed that auditory information influences binocular rivalry caused by different directions of movement. Binocular rivalry is a phenomenon in which, when different visual stimuli are presented to the left and right eyes, the two appear to compete and appear alternately. It is known that auditory information influences which one becomes dominant. For example, when random dots moving rightward is presented to the right eye and random dots moving leftward to the left eye, which becomes dominant depends on motion of auditory stimulus presented simultaneously. In the present research, we investigated the effect on binocular rivalry between upward and downward movements of visual stimuli by tone changes, which are said to be related to vertical movement. Results showed that upward movement was dominant with sound stimuli with rising tones. This result suggests that changes in tone is linked to up-and-down movements in subconscious and at non-semantic level, and also that binocular rivalry can be effectively used to investigate audiovisual integration processes.

[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] Yamamoto, K., Shioiri, S. Auditory pitch modulation of binocular rivalry, European Conference on Visual Perception 2022, Nijmegen, the Netherlands, August-September 2022
[2] Alexander Raevskiy , Ivan Bubnov , Yi-Chuan Chen , and Nobuyuki Sakai, Differences in Color Representations of Tastes: Cross-cultural Study Among Japanese, Russian and Taiwanese. P.-L. P. Rau (Ed.): HCII 2022, LNCS 13311, pp. 378–395, 2022. https://doi.org/10.1007/978-3-031-06038-0_28
[3] Alexander Raevskiy, Shuichi Sakamoto, and Nobuyuki Sakai Psychoacoustic Study of Japanese Mimetics for Food Textures. K. Kondo et al. (eds.), Advances in Intelligent Information Hiding and Multimedia Signal Processing, Smart Innovation, Systems and Technologies 339, https://doi.org/10.1007/978-981-99-0105-0_37
[4] Renjun Miao R. , Kato, H. Hatori, Y. Sato Y., and Shioiri, S. 2022. Analysis of Facial Expressions for the Estimation of Concentration on Online Lectures. In *World Conference on Computers in Education(IFIP WCCE, 2022)*, Hiroshima, Japan, 4G-1.
[5] Kato, H., Takahashi, K., Hatori, Y., Sato, Y. and Shioiri, S. 2022. Prediction of Engagement from Temporal Changes in Facial Expression. In *World Conference on Computers in Education(IFIP WCCE, 2022)*, Hiroshima, Japan, 9G-2.
[6] Kato, H., Takahashi, K., Hatori, Y., Sato, Y. and Shioiri, S.2022. Prediction of engagement from facial expressions: effect of dynamic factors. In *The 18th International Conference on Intelligent Information Hiding and Multimedia Signal Processing (IIHMSP-2022)*. Kitakyushu, Japan. IIHMSP-2022-IS05-04.

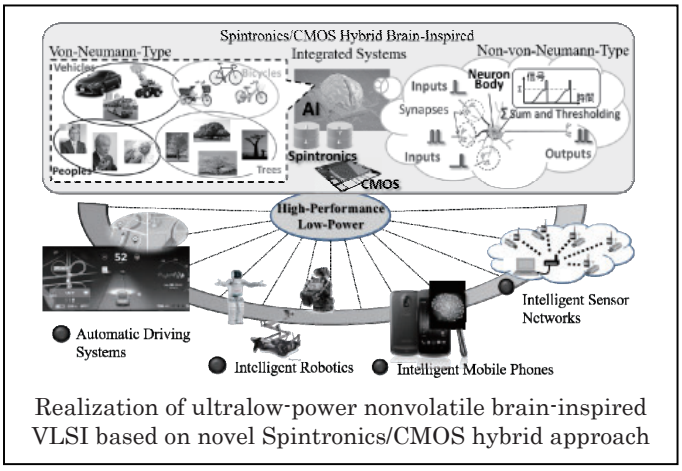
Spintronics/CMOS Hybrid Brain-Inspired Integrated Systems

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

Takahiro Hanyu, Professor
Tetsuo Endoh, Professor
Tao Li, Assistant Professor

[Research Target and Activities]

The objective of our research is to pave the path for an innovative AI hardware approach, spanning from the fundamental science of material and information to devices, circuits, architectures, and software technologies, in order to develop a novel brain-inspired computing hardware system for precise and real-time processing of information value judgment, selection, and refusal. This year, this project established the experimental environment for the validation of hybrid spintronics/CMOS brain-inspired systems by 2021, laying the foundation for assessing the efficacy and accuracy of brain-inspired VLSI processors. This year's primary objective is to design a spintronics/CMOS hybrid brain-inspired circuit module containing an adaptive quantization module and an approximate multiplier module. The progress of these two research achievements and the associated research results this year are presented as follows:



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

① **Adaptive and energy-efficient quantization module for Spintronic/CMOS hybrid brain-inspired systems.**

For the development of spintronic/CMOS hybrid brain-inspired systems, it is essential to achieve adaptive transformation of different data representation formats. This project proposes a new adaptive and energy-efficient quantization technique and systematically demonstrates its efficacy from algorithm to hardware module for industrial IoT applications, including precise navigation for autonomous vehicles and precise classification of deep neural networks. The proposed quantization method combines an adaptive conversion function from floating-point to fixed-point binary representations and an adaptive radix-point determination function, ensuring adequate resolution and minimal error loss of the fixed-point inputs to the edge AI modules. The experimental results indicate that the quantization error in the proposed quantization technique contributes negligible errors to the navigation solutions of the strapdown inertial navigation system and the classification accuracy of the top-1 and top-5 DNNs. In addition, a quantization-on-module is designed, synthesized, and routed in accordance with the proposed quantization technique.

② **Hybrid signed convolution module for energy-efficient STT-MRAM-based spintronic/CMOS hybrid brain-inspired systems**

STT-MRAM is the most promising memory for the fast development of spintronics/CMOS hybrid brain-inspired systems in consumer electronics because of its low power consumption, rapid processing speed, and high endurance. To enhance the functional diversity and energy efficiency of spintronics/CMOS hybrid brain-inspired systems, a hybrid signed convolution module with the architecture of an unsigned divide-and-conquer multiplier is proposed in this project. The proposed multiplier framework enables three

multiplication modes, significantly increasing the multiplier's versatility for next-generation brain-inspired systems. The proposed multiplier-based convolution module has the lowest average power consumption for 8-bit convolution when compared to state-of-the-art convolution accelerators. Utilizing power-gating technology on STT-MRAM, the proposed convolution module keeps acceptable precision in high-bit multiplication while reducing energy consumption by a factor of 22. Incorporating a hybrid convolution module further enhances power efficiency by 8x, resulting in a 175x decrease in power efficiency for spintronics/CMOS hybrid brain-inspired systems.

[Staff]

Professor: Takahiro Hanyu, Ph.D

Professor: Tetsuo Endoh, Ph.D.

Assistant Professor: Tao Li, Ph.D.

[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.

Tetsuo Endoh received his Ph.D. 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. Since 2012, he has been a professor at the Graduate School of Engineering and director of CIES and CSIS at 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), the SSDM Paper Award (2012), the 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).

Tao Li received a Ph.D. in Navigation, Guidance, and Control from the Graduate School of Engineering, Harbin Engineering University, in June 2016. He worked as a specially appointed researcher at the Institute of Innovative Science and Technology, Tokai University, in October 2016. In May 2020, he served as an assistant professor at the Center for Innovative Integrated Electronic Systems and Graduate School of Engineering, Tohoku University. Since April 2023, he has been an assistant professor at the Research Institute of Electrical Communication, Tohoku University.

[Papers]

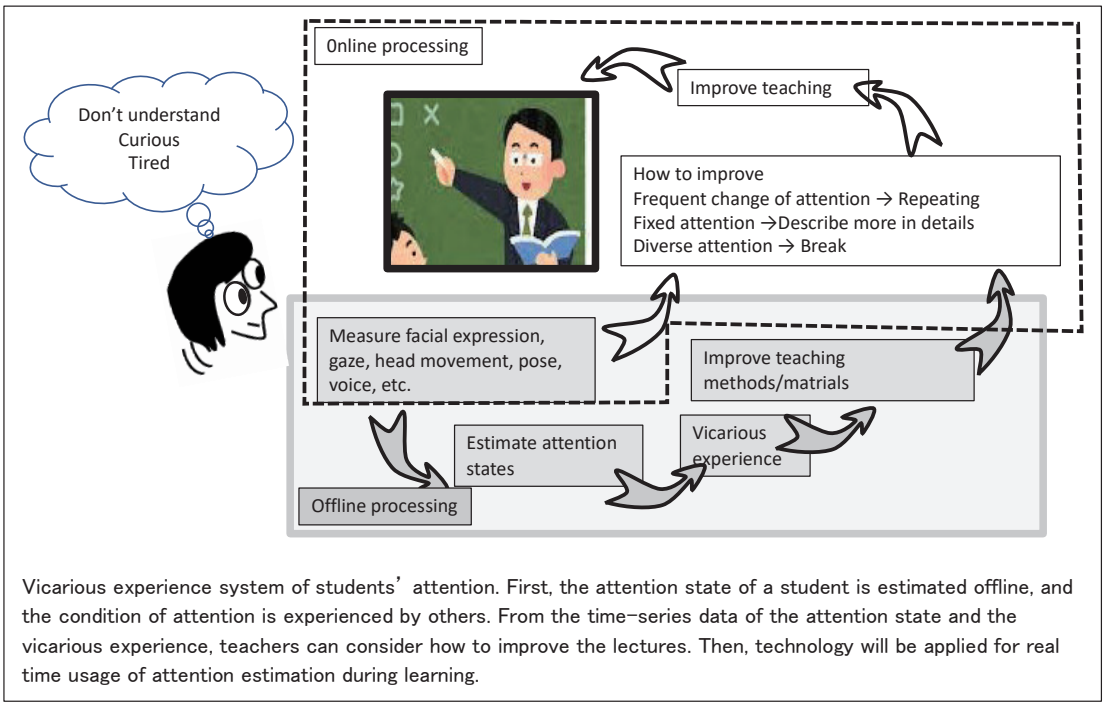
[1] T. Li, Y. Ma, K. Yoshikawa and T. Endoh, "Hybrid Signed Convolution Module With Unsigned Divide-and-Conquer Multiplier for Energy-Efficient STT-MRAM-Based AI Accelerator," in *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, doi: 10.1109/TVLSI.2023.3245099.

[2] T. Li, Y. Ma, and T. Endoh, "Neuromorphic processor-oriented hybrid Q-format multiplication with adaptive quantization for tiny YOLO3," *Neural Computing and Applications,* **35**, 11013–11041 2023, doi: https://doi.org/10.1007/s00521-023-08280-y.

[3] T. Li, Y. Ma and T. Endoh, "From Algorithm to Module: Adaptive and Energy-Efficient Quantization Method for Edge Artificial Intelligence in IoT Society," in *IEEE Transactions on Industrial Informatics*, 2022, doi: 10.1109/TII.2022.3223222.

Exploratory Research Division

Development of the education support system with estimation of attention states



Vicarious experience system of students' attention. First, the attention state of a student is estimated offline, and the condition of attention is experienced by others. From the time-series data of the attention state and the vicarious experience, teachers can consider how to improve the lectures. Then, technology will be applied for real time usage of attention estimation during learning.

[Research Target and Activities]

While online classes and conferences have become popular and the limitations compared to face-to-face meetings have been identified, online communication is attracting many people in terms of new types of information usages. According to rapid increase of online classes, it is an urgent issue to research of mental state estimation for the appropriate and effective use of video teaching materials, tablet teaching materials, etc., are expected in the field of education. The purpose of the project is to estimate the attention state from facial expressions and voices, constructing a model. For the purpose, we measure facial images and voices as well as EEG during learning. To analyze these time varying measures online, it is necessary to use high speed and performance system based on the latest AI technology and FPGA (Field Programmable Gate Array).

[Staff]

Satoshi Shioiri,
Project Leader, Professor

[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.

[Papers]

[1] Miao R. , Kato, H. Hatori, Y. Sato Y., and Shioiri, S. 2022. Analysis of Facial Expressions for the Estimation of Concentration on Online Lectures. In *World Conference on Computers in Education(IFIP WCCE, 2022)*, Hiroshima, Japan, 4G-1.

[2] Kato, H., Takahashi, K., Hatori, Y., Sato, Y. and Shioiri, S. 2022. Prediction of Engagement from Temporal Changes in Facial Expression. In *World Conference on Computers in Education(IFIP WCCE, 2022)*, Hiroshima, Japan, 9G-2.

[3] Kato, H., Takahashi, K., Hatori, Y., Sato, Y. and Shioiri, S.2022. Prediction of engagement from facial expressions: effect of dynamic factors. In *The 18th International Conference on Intelligent Information Hiding and Multimedia Signal Processing (IIHMSP-2022)*. Kitakyushu, Japan. IIHMSP-2022-IS05-04.

Exploratory Research Division

Drone Utilization Technologies to Realize a Symbiotic Society

Yoshifumi KITAMURA, Professor

[Research Target and Activities]

This project aims to develop core technologies of interactive drone content for real industrial use including Drones have been playing an increasingly active role in recent years, but their utilization requires consideration of sustainability and accessibility. In order to realize a symbiotic society, this study addresses to develop key technologies for the utilization of drones that can be used by anyone by introducing an open source framework and environmentally friendly technologies.

[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] Maakito Inoue, Kazuki Takashima, Kazuyuki Fujita, Yoshihumi Kitamura. BirdViewAR: Surroundings-aware Remote Drone Piloting Using an Augmented Third-person Perspective, Proc of the 2023 CHI Conference on Human Factors in Computing Systems.

IT21 Center
Exploratory Research Division
Wireless IoT Technology for Smart Factories

Toward smart factories with next generation wireless IoT

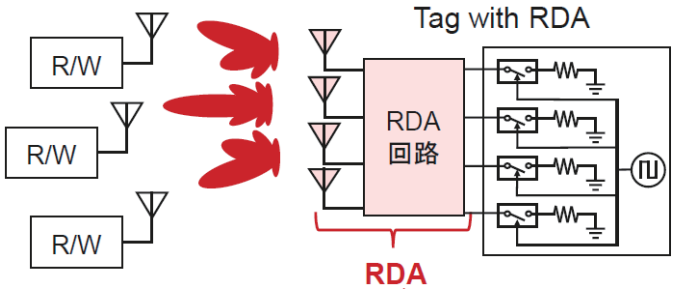


Fig.1 WiFi-backscatter communication with Retro-directive array (RDA)

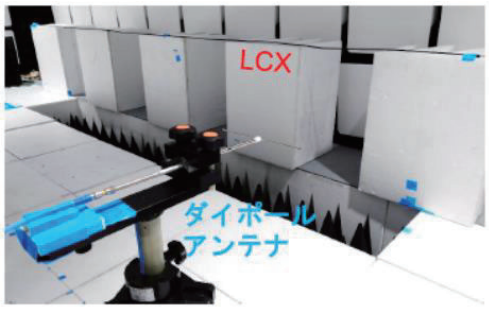


Fig.2 Leaky coaxial cable (LCX) communication system

Noriharu Suematsu, Professor (Project Leader)
Takashi Shiba, Specially appointed Professor
Jean Temga, Research fellow
Suguru Kameda, Visiting Professor (Hiroshima University)

[Research Target and Activities]

Beyond 5G(B5G)/6G will offer us not only high speed/high throughput but also low latency (real-time)/massive connection wireless IoT communication. The factories equipped with B5G/6G (i.e. smart factories) is a key of manufacturing revolution which is called as “Industry 4.0.”
This division conducts exploratory research on establishing the following two technologies.
(a) measurement and analysis of smart factory’s real-time radio environment in which multiple IoT communication systems (such as local 5G, wireless-LAN, Bluetooth and WPT) coexist.
(b) next generation wireless system, transceiver hardware, signal processing technologies for next generation smart factory’s wireless IoT communication in 6G era.
This year we have developed WiFi-backscatter communication using Retro-directive array (RDA) and have started the development of LCX communication system for smart factories.
Fig.1 shows WiFi-backscatter communication with RDA and Fig.2 shows evaluation setup of LCX communication system.

[Papers]

[1] Y. Honma, J. Temga, T. Shiba, N. Suematsu, "A Compact 5.2 GHz Reflection-Type Retrodirective Array Using Butler Matrix with Broadside Couplers," 2022 European Microwave Conference (EuMC), pp. 393-396, Sep. 2022.
[2] Y. Honma, J. Temga, T. Furuichi, T. Shiba, N. Suematsu, "A 5 GHz-Band 2×2 Reflection-Type Retrodirective Array with Stacked Stripline Phase Conjugate Circuit," 2022 Asia-Pacific Microwave Conference (APMC), pp. 151-153, Nov. 2022.

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: Shigeo Sato, Professor

Nobuyuki Sato, Assistant Professor

Maho Abe, Technical Staff　Hiroyuki Yagyu, 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 the Research Institute of Electronic Communication (hereafter RIEC), based on the concept of flexible information processing that reflects human intentions and the environment.

Figure RIEC server room

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

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

[Status Report of the Flexible Information System Center]

At the Flexible Information System Center, we manage and operate the server system and the information network underlying the academic research conducted throughout 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.
- Managing the information system accounts.
- Constructing and renewing the official RIEC website.
- Developing and publishing videos containing the events and conferences associated with RIEC activities.
- Establish and maintain an online conference system in the conference room, and support the operation of online events.
- Improving on the security measures of mobile devices checked out of the RIEC premises.
- Operating the system with backup power sources under scheduled power shutdowns.

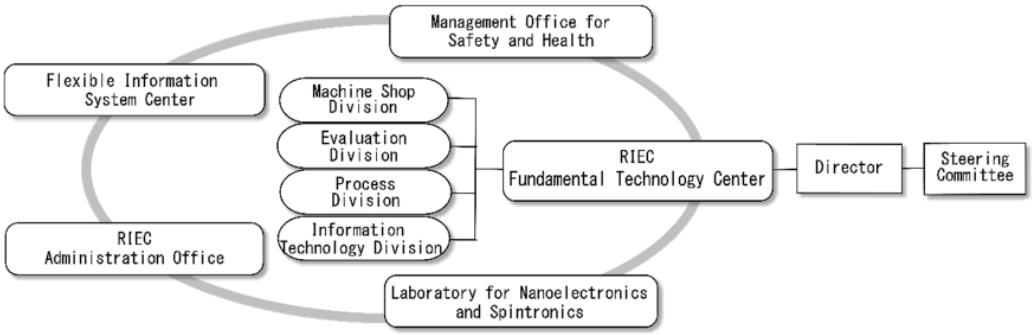
[Staff]

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

(2) Staff
Director (Professor): Go Hasegawa, Dr.
Technical Official: Kenji Ota
Technical Official*: Yuko Maruyama
Technical Support Member: Mutsumi Shuto, Kiwamu Sumino

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 94 machining products. About 10% of the requests were from outside the institute.

2. Evaluation Division

20 laboratories and 2 external research institute and company utilized the evaluation and measurement apparatuses for shared usage (the utilization time was 2,666 hours). Technical assistance on the use of liquid helium was provided for 3 laboratories. 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, 345Electron-beam lithography products, 39 photomasks and 21 commissioned analyzes such as focused ion beam systems were supplied. Operation management and maintenance were provided for operating the clean rooms of the Laboratory for Nanoelectronics and Spintronics.

4. Information Technology Division

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

[Staff]

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

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 top-down and body-related attention and found that these two are not controlled by a common process.

[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 2022, 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. This year, in order to promote research on brain-morphic computing from a wide range of perspectives, including brain science, spintronics devices, analog and digital integrated circuits, cultured neural circuits, and nonlinear complex dynamics, we are cooperating with the JST CREST Sato project and the Yamamoto project of Grant-in-Aid for Transformative Research Areas (B), which was adopted through full support by this research group. We also organized and presented our research in the joint workshop of Nonlinear Workshop and Grant-in-Aid for Scientific Research (A), in which Horio serves as a representative.

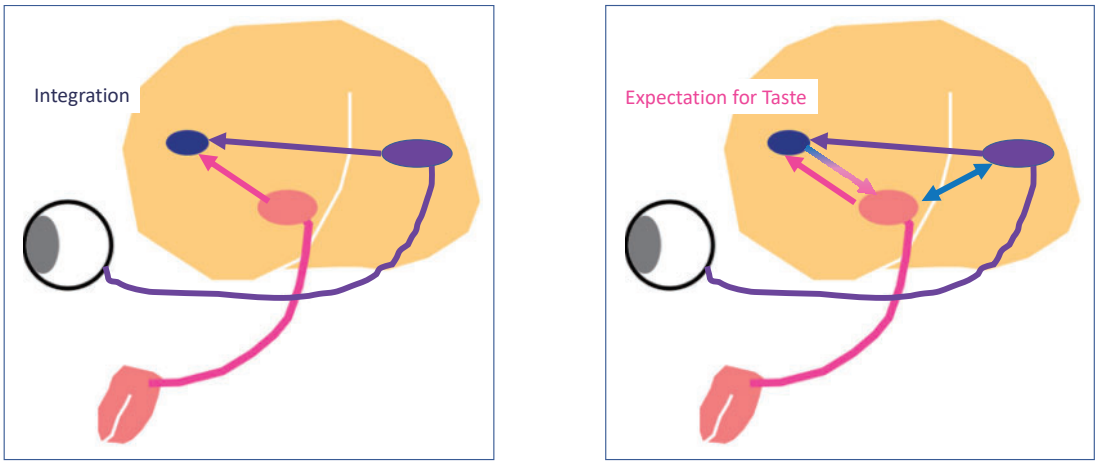
[Group of developing the AI clone system]

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 started a project of IT21center, Development of the education support system with estimation of attention states, this year.

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 psycholinguistic research on onomatopoeia on food texture; the neural and cognitive mechanisms underlying face recognition and face aesthetics investigated by fMRI and fNIRS, etc. We have also started the cognitive studies about the effect of audition on binocular rivalry, the interactive mechanisms of audition with somatosensation, and the phenomena of the effects of top-down processing on food recognition and palatability evaluastion.

[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] Alexander Raevskiy , Ivan Bubnov , Yi-Chuan Chen , and Nobuyuki Sakai, Differences in Color Representations of Tastes: Cross-cultural Study Among Japanese, Russian and Taiwanese. P.-L. P. Rau (Ed.): HCII 2022, LNCS 13311, pp. 378–395, 2022. https://doi.org/10.1007/978-3-031-06038-0_28

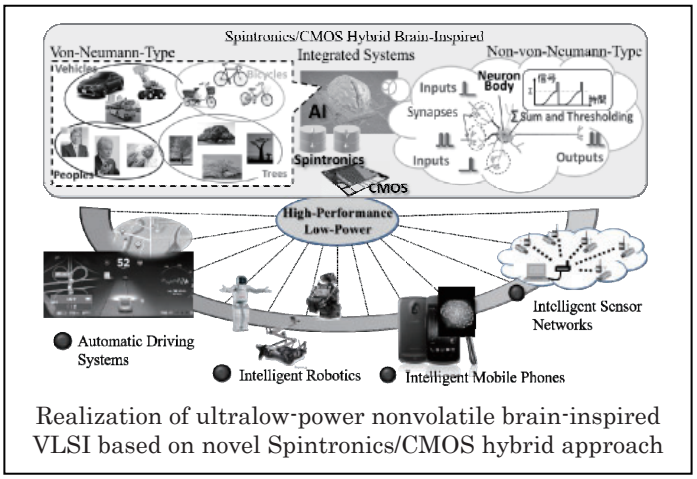
[2] Alexander Raevskiy, Shuichi Sakamoto, and Nobuyuki Sakai Psychoacoustic Study of Japanese Mimetics for Food Textures. K. Kondo et al. (eds.), Advances in Intelligent Information Hiding and Multimedia Signal Processing, Smart Innovation, Systems and Technologies 339, https://doi.org/10.1007/978-981-99-0105-0_37

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 Tao Li, Assistant Professor

[Research Target and Activities]



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

The objective of our research is to pave the path for an innovative AI hardware approach, spanning from the fundamental science of material and information to devices, circuits, architectures, and software technologies, in order to develop a novel brain-inspired computing hardware system for precise and real-time processing of information value judgment, selection, and refusal. This year, this project established the experimental environment for the validation of hybrid spintronics/CMOS brain-inspired systems by 2021, laying the foundation for assessing the efficacy and accuracy of brain-inspired VLSI processors. This year's primary objective is to design a spintronics/CMOS hybrid brain-inspired circuit module containing an adaptive quantization module and an approximate multiplier module. The progress of these two research achievements and the associated research results this year are presented as follows:

①. **Adaptive and energy-efficient quantization module for Spintronic/CMOS hybrid brain-inspired systems.**

For the development of spintronic/CMOS hybrid brain-inspired systems, it is essential to achieve adaptive transformation of different data representation formats. This project proposes a new adaptive and energy-efficient quantization technique and systematically demonstrates its efficacy from algorithm to hardware module for industrial IoT applications, including precise navigation for autonomous vehicles and precise classification of deep neural networks. The proposed quantization method combines an adaptive conversion function from floating-point to fixed-point binary representations and an adaptive radix-point determination function, ensuring adequate resolution and minimal error loss of the fixed-point inputs to the edge AI modules. The experimental results indicate that the quantization error in the proposed quantization technique contributes negligible errors to the navigation solutions of the strapdown inertial navigation system and the classification accuracy of the top-1 and top-5 DNNs. In addition, a quantization-on-module is designed, synthesized, and routed in accordance with the proposed quantization technique.

②. **Hybrid signed convolution module for energy-efficient STT-MRAM-based spintronic/CMOS hybrid brain-inspired systems**

STT-MRAM is the most promising memory for the fast development of spintronics/CMOS hybrid brain-inspired systems in consumer electronics because of its low power consumption, rapid processing speed, and high endurance. To enhance the functional diversity and energy efficiency of spintronics/CMOS hybrid

brain-inspired systems, a hybrid signed convolution module with the architecture of an unsigned divide-and-conquer multiplier is proposed in this project. The proposed multiplier framework enables three multiplication modes, significantly increasing the multiplier's versatility for next-generation brain-inspired systems. The proposed multiplier-based convolution module has the lowest average power consumption for 8-bit convolution when compared to state-of-the-art convolution accelerators. Utilizing power-gating technology on STT-MRAM, the proposed convolution module keeps acceptable precision in high-bit multiplication while reducing energy consumption by a factor of 22. Incorporating a hybrid convolution module further enhances power efficiency by 8x, resulting in a 175x decrease in power efficiency for spintronics/CMOS hybrid brain-inspired systems.

[Staff]

Professor: Tetsuo Endoh, Ph.D.

Assistant Professor: Tao Li, Ph.D.

[Profile]

Tetsuo Endoh received his Ph.D. 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. Since 2012, he has been a professor at the Graduate School of Engineering and director of CIES and CSIS at 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), the SSDM Paper Award (2012), the 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).

Tao Li received a Ph.D. in Navigation, Guidance, and Control from the Graduate School of Engineering, Harbin Engineering University, in June 2016. He worked as a specially appointed researcher at the Institute of Innovative Science and Technology, Tokai University, in October 2016. In May 2020, he served as an assistant professor at the Center for Innovative Integrated Electronic Systems and Graduate School of Engineering, Tohoku University. Since April 2023, he has been an assistant professor at the Research Institute of Electrical Communication, Tohoku University.

[Papers]

[1] T. Li, Y. Ma, K. Yoshikawa and T. Endoh, "Hybrid Signed Convolution Module With Unsigned Divide-and-Conquer Multiplier for Energy-Efficient STT-MRAM-Based AI Accelerator," in *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, doi: 10.1109/TVLSI.2023.3245099.

[2] T. Li, Y. Ma, and T. Endoh, "Neuromorphic processor-oriented hybrid Q-format multiplication with adaptive quantization for tiny YOLO3," *Neural Computing and Applications,* **35**, 11013–11041 2023, doi: https://doi.org/10.1007/s00521-023-08280-y.

[3] T. Li, Y. Ma and T. Endoh, "From Algorithm to Module: Adaptive and Energy-Efficient Quantization Method for Edge Artificial Intelligence in IoT Society," in *IEEE Transactions on Industrial Informatics*, 2022, doi: 10.1109/TII.2022.3223222.

Center for Science and Innovation in Spintronics (CSIS)

＜About the Center＞

Establishment : January 30, 2018

Organization : Director: Yoshio Hirayama (Specially Appointed Professor)
Number of academic members: 43 (including 5 full-time and 37 concurrent members)

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 2022＞

- **Promotion of world-leading research in spintronics**

  Excellent 5 proposals, which are creative and expected to make outstanding achievements, were adopted to the international cooperative research projects and their research and outsourcing expenses were supported by CSIS. The submission fees and/or article processing charges of high impact-factor journals were also supported.

- **Fostering excellent early-career researchers**

  Excellent early-career researchers, 4 persons from foreign countries, were employed as assistant professors to promote collaborations with researchers of domestic and foreign institutions. An associate professor was employed as PI in the CSRN division and established the laboratory for the interdisciplinary research of quantum sensing and spintronics.

- **Promoting international academic exchange**

  The laboratory for international collaboration with the University of Chicago was operated continuously. The 6th International Symposium for the Core Research Clusters for Materials Science and Spintronics was held via online in October, 2022. The following international meetings were also co-sponsored or supported by CSIS:

  - EPSRC International Network for Spintronics Early Carrier Researchers Meeting (May, 2022)
  - The 2022 Spintronics Workshop on LSI (June, 2022)
  - Materials Development Towards Energy Efficient Magnetic Memory (December, 2022)
  - International Workshop of Spin/Quantum Materials and Devices (February, 2023)
  - 2nd Online RIEC International Workshop on Spintronics (March-April, 2023)

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

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

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

＜Major activities in FY2021＞

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

CIES has developed a variety of innovative technologies with world-first 300mm wafer process line and facilities operated by the university for prototype manufacturing and characterizing spintronics integrated circuits compatible with world-class companies, and has made progress in developing IoT and AI systems that require ultra-low power consumption.

Specifically, in the field of spintronics, new iPMA-type Hexa-technology in Magnetic Tunnel Junctions (MTJ) has demonstrated data retention durability at 260°C and over 10 million rewrite durability at the time of manufacturing advanced microcomputers. The result paves the way for high-performance and large-capacity embedded non-volatile memory for X nm generation advanced microcomputers. In 2022, our university's proposal "Innovative spintronics X semiconductor research hub (Director: Tetsuo Endoh)" was adopted by MEXT "Initiative to Establish Next-generation Novel Integrated Circuits Centers (X-NICS)". Over a period of 10 years, we will promote the creation of innovative low-power semiconductors and the development of advanced human resources in collaboration with collaborating and cooperating organizations. In addition, it has been adopted by NEDO “Efficient Design and Demonstration of AI Processor using CMOS / Spintronics Hybrid Technology” and is working with the RIEC to develop technology to accelerate the industrial application of AI edge computing. In the field of power electronics, MEXT “Research and Development of Basic Technologies for Creating Innovative Power Electronics” adopted in 2021 further promoted research and development of integrated power electronics. We are working to achieve higher power density (miniaturization) and higher efficiency by researching and developing circuit systems that take full advantage of the superior performance of wide bandgap devices such as SiC and GaN, and by applying passive components that are optimal for such circuit systems, we will develop high-performance inverters for next-generation EVs and power supplies for data centers. Utilizing the three core technologies of spintronics technology, AI hardware technology and power electronics technology, which are the world's most advanced technologies that have been researched and developed at CIES, we aim to develop IoT/AI system, which is indispensable for realizing carbon neutrality and requires ultra-low power consumption.

Aiming to contribute to the development of the innovative integrated electronics business and further advancement of industry-academia collaboration, Power Spin Inc., a startup company from Tohoku University, is now in its fifth year, and it has been put into practical use based on the technology and know-how of this center. In addition to Miyagi Prefecture, the Miyagi Advanced Electronics and Machinery Industry Association, the Miyagi Automotive Industry Promotion Council, Iwate Prefecture, Iwate Semiconductor and Electronics Industries Promotion Conference, local and local companies in Yamagata Prefecture was added, and regional cooperation was expanded with cooperation of the METI Tohoku. In 2022, based on Japan's semiconductor strategy, the METI Tohoku played a central role in establishing the TOHOKU Study Group on Design of Semiconductor and Electronics Industry. Director Endoh participates in this study group, and in cooperation with the Technology Co-creation for Semiconductor of Tohoku University, etc., we are considering human resource development according to the characteristics of the region and promotion such as strengthening the supply chain.

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.

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: 47 (RIEC, Graduate School of Engineering, 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, Graduate School of Agricultural Science, Graduate School of International Cultural Studies, Institute of Development, Aging and Cancer, International Research Institute of Disaster Science, Cyberscience Center, The Center for Academic Resources and Archives, Unprecedented-scale Data Analytics Center)

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 2022＞

1. We have started 15 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 105 papers and 114 presentations (including 24 invited talks).
2. We organized an international symposium “Symposium of Yotta Informatics – Research Platform for Yotta-Scale Data Science 2022” and co-organized a RIEC international symposium “Tohoku U - NTU Symposium: When AI Meets Human Science," and invited many researchers from inside and outside of Japan. We also conducted International Workshop on Emerging ICT and three special sessions of IEICE meetings.
3. The issue of Interdisciplinary Information Sciences (IIS), where we edited a special section, “New informatics paradigm to manage quality and value of information” has published.

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 (Specially Appointed Professor)
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 FY2022＞

Under the influence of COVID-19 in FY2022, the students of GP-Spin arranged 5 talks by researchers of Tohoku University in “EPSRC International Network for Spintronics Early Carrier Researchers Meeting” held in May, 2022. The Students’ Workshop, including 4 invited talks and presentations by the students of GP-Spin, was held as a part of the 32nd Joint-Interlaboratory Workshop on Nano-Magnets in February, 2023. The workshops to improve the students’ skills of presentation in English were held twice in June and October, 2022.

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

＜About the Center＞

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

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

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

＜Major Achievements in 2022＞

The program received an A grade from the interim evaluation conducted in the previous fiscal year. Although the program as a whole received a high evaluation, some points were pointed out and efforts were made to improve them. In FY2022, the Project Based Learning (PBL) courses, which are unique to the AIE Graduate School of Excellence, were conducted in a face-to-face format, and a symposium on learning outcomes was held after the completion of the program. After completing the course, a symposium was held and students made presentations on the results of their studies in the course. In addition, six AIE lectures and an international symposium were held, in which prominent professors from Japan and abroad gave lectures on a wide range of topics, from basic technologies to applications and issues in the social practice of artificial intelligence electronics. All students in the program presented their research in English at the international symposium. We recruited and selected students for the fifth year, and 25 new students (7 new M1 students, 11 new M2 students, and 7 new D1 students) were selected.

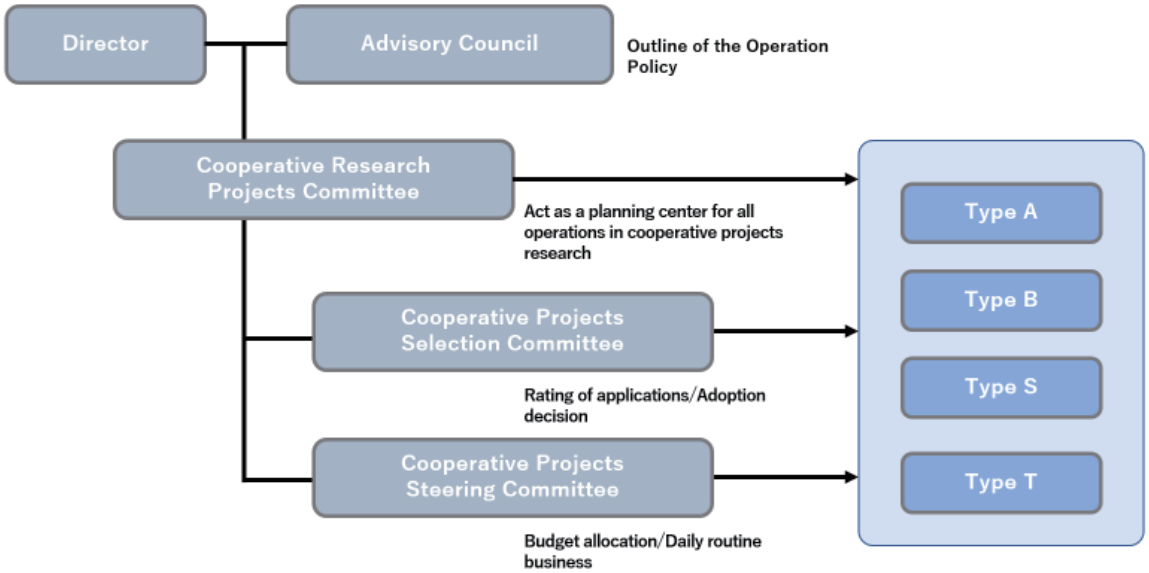
4. Nation-wide Cooperative Research Projects

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

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

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

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



Nation-wide Cooperative Research Projects List 2022

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R02/A01	Development of graphene based devices for terahertz applications	**MEZIANI Yahya Moubarak** Department Fisica Aplicada, Salamanca University	**OTSUJI Taiichi**
R02/A02	Analyses and mathematical modeling of the function of artificial neuronal circuit	**TANII Takashi** Faculty of science and engineering, Waseda University	**YAMAMOTO Hideaki**
R02/A03	Development of optoelectronic devices based on two-dimensional materials	**UCHINO Takashi** Department of Electrical and Electronic Engineering, Faculty of 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/A10	Investigation of physical structure model of high-k/Ge interface affected by fabrication processes	**OTANI Yohei** Department of Mechanical and Electrical Engineering, Faculty of 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/A13	Ultra-low-latency video coding for 8K high-resolution image sensing	**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	**SUEMATSU Noriharu**
R02/A15	A study on over 100GHz-band/optical fiber feed direct digital RF transceiver	**SUEMATSU Noriharu** Research Institute of Electrical Communication, Tohoku University	**SUEMATSU Noriharu**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
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/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	The shape variation of human pinna and its effect on the acoustical transfer function.	**ITO Masashi** Faculty of Engineering, Tohoku Institute of Technology	**SAKAMOTO Shuichi**
R02/A22	Research on the development of a new generation IoT platform	**ZABIR Salahuddin Muhammad Salim** Department of Creative Engineering, National Institute of Technology, Tsuruka College	**HASEGAWA Go**
R02/A23	Exploring and Understanding Touch Interaction using a Slidable-Sheet on Smart Devices	**FUJITA Kazuyuki** Research Institute of Electrical Communication, Tohoku University	**FUJITA Kazuyuki**
R02/A24	Investigating cultural issues for the design of touch-based interactive D-FLIP photo management system	**CHINTAKOVID Thippaya** Department of Library Science, Faculty of Arts, Chulalongkorn University	**KITAMURA Yoshifumi**
R02/A25	Multimodal Data Flow Processing Platform for Enhancing Human Abilities	**MINENO Hiroshi** Faculty of Informatics, Shizuoka University	**HASEGAWA Go**
R02/A29	Cultural background and auditory selective attention	**KIM Sungyoung** ECT Engineering Technology, Rochester Institute of Technology	**SAKAMOTO Shuichi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
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**
R03/A01	Radiation effect study on spintronics devices for space applications	**WATANABE Kyota** Research and Development Directorate, Japan Aerospace Exploration Agency	**FUKAMI Shunsuke**
R03/A02	Development of Multi-Functional Integrated Circuit on Si/Ge Hybrid Platform	**YAMAMOTO Keisuke** Faculty of Engineering Sciences, Kyushu University	**SAKURABA Masao**
R03/A03	Control of spin dynamics in non-magnetic materials	**ISHIHARA Jun** Department of Applied Physics, Faculty of Science, Tokyo University of Science	**KANAI Shun**
R03/A04	Creation of Bio-Medical Devices Utilizing Non-Equilibrium Plasma-Producing Reactive Species	**KANEKO Toshiro** Graduate School of Engineering, Tohoku University	**HIRANO Ayumi**
R03/A05	Heusler magnetic Weyl semimetal :Toward a voltage-controlled non-volatile magnetic memory	**CHIBA Takahiro** General Education, National Institute of Technology, Fukushima College	**TSUJIKAWA Masahito**
R03/A06	R&D on radiation response of quantum devices	**KISHIMOTO Yasuhiro** Research Center for Neutrino Science, Tohoku University	**OTSUKA Tomohiro**
R03/A07	Development of Quantum Device based on Atomically Thin Layered Materials	**KATO Toshiaki** Graduate School of Engineering, Tohoku University	**OTSUKA Tomohiro**
R03/A09	Research of on-chip THz array antenna for ultra-wideband communication	**KANAYA Haruichi** Graduate School of Information Science and Electrical Engineering, Kyushu University	**SUEMATSU Noriharu**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R03/A10	High frequency chaos circuits using resonant tunneling diodes and their applications	**MAEZAWA Koichi** Graduate School of Science and Engineering, University of Toyama	**OTSUJI Taiichi**
R03/A11	Millimeter-wave large-scale array antenna for wireless terminal application	**YOSHIDA Satoshi** Research Field in Engineering, Science and Engineering Area, Research and Education Assembly, Kagoshima University	**SUEMATSU Noriharu**
R03/A12	Study on energy harvesting and meta-surface applied for 5G / IoT	**MARUYAMA Tamami** Department of Production Systems Engineering, National Institute of Technology, Hakodate College	**SUEMATSU Noriharu**
R03/A13	Study of delay-sensitive and seamless access networks using widely frequency selectable optoelectronics integrated devices	**YOSHIMOTO Naoto** Faculty of Science and Technology, Chitose Institute of Science and Technology	**OTSUJI Taiichi**
R03/A14	Mixed Reality for IoT and Robotics: Opportunities and Challenges for Immersive Human-Robot Interaction	**SUZUKI Ryo** Department of Computer Science, University of Calgary	**KITAMURA Yoshifumi**
R03/A15	Reconfigurable Head-Mounted Displays Enabling Real-world Interactions	**KIYOKAWA Kiyoshi** Graduate School of Science and Technology, Nara institute of science and technology	**KITAMURA Yoshifumi**
R03/A16	An investigation on spatio-temporal characteristics of auditory selective attention	**TERAOKA Ryo** Graduate School of Humanities and Social Sciences, Kumamoto University	**SAKAMOTO Shuichi**
R03/A17	Study on sound space perception under limited binaural cue condition	**MORIKAWA Daisuke** Faculty of Engineering, Toyama Prefectural University	**SAKAMOTO Shuichi**
R03/A20	Neuromorphic Systems using Thin-Film Memcapacitors	**KIMURA Mutsumi** Faculty of Science and Technology, Ryukoku University	**HORIO Yoshihiko**
R03/A22	IoT security technologies	**OGUMA Hiroshi** Department of Electronics and Computer Engineering, National Institute of Technology, Toyama College	**HOMMA Naofumi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R03/A23	Development of Advanced Harmonized Agent Platform	**UCHIYA Takahiro** Information Technology Center, Nagoya Institute of Technology	**SAKAMOTO Shuichi**
R03/A25	Creation of device informatics and application to Beyond 5G devices	**FUKIDOME Hirokazu** Research Institute of Electrical Communication, Tohoku University	**FUKIDOME Hirokazu**
R03/A26	Quantum research based on integration of experimental, theoretical and data science	**FUKUHARA Takeshi** Research Institute of Electrical Communication, Tohoku University	**OTSUKA Tomohiro**
R03/A27	Investigation of contactless power transmission in a long distance	**INAMORI Mamiko** Department of Electrical and Electronic Engineering, Tokai University	**SUEMATSU Noriharu**
R03/A28	Embodiment of space perception: anisotropy and individual difference	**TERAMOTO Wataru** Graduate School of Social and Cultural Sciences, Kumamoto University	**SAKAMOTO Shuichi**
R03/A29	Application of high-performance soft magnetic alloys to advanced devices	**SUZUKI Shigeru** Micro System Integration Center, Tohoku University	**ISHIYAMA Kazushi**
R03/A30	Effects of body vibration generated from audio-visual signal on perceived reality in multimodal contents	**CUI Zhenglie** Media Informatics, Aichi University of Technology	**SAKAMOTO Shuichi**
R03/A31	Research on the formation of a gravity observation network using optical communication technologies and the monitoring of volcanic activities	**KASAI Keisuke** Research Institute of Electrical Communication, Tohoku University	**KASAI Keisuke**
R03/A32	Hardware Technology for Brain Computing and its Application to Edge Computing	**SATO Shigeo** Research Institute of Electrical Communication, Tohoku University	**SATO Shigeo**
R04/A01	Coplanar waveguide size and magnetization angle dependence of magnetization dynamics in CoFeB-MgO magnetic tunnel junction structure measured by spin rectification ferromagnetic resonance	**Eli Christopher Inocencio Enobio** Department of Physics, Mindanao State University-Iligan Institute of Technology	**FUKAMI Shunsuke**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R04/A02	Development of intraluminal NMR receive coil for high field MRI	**LEE Sang-Seok** Faculty of Engineering, Tottori University	**SUEMATSU Noriharu**
R04/A03	Japan-Russia International collaborative research on boosting a performance of a large-area THz photoconductive emitter	**DMITRY Ponomarev** Laboratory of high-power microwave and mm-wave applications, Institute of ultra high frequency semiconductor electronics of Russian	**OTSUJI Taiichi**
R04/A04	Study on Silicidation Reaction of Metal Nanodots with SiH4	**MIYAZAKI Seiichi** Graduate School of Engineering, Nagoya University	**SATO Shigeo**
R04/A05	Study of magnetic, dielectric and optical properties of nanomaterials for Terahertz applications	**AMINE El Moutaouakil** Department of Electrical Engineering, United Arab Emirates University	**OTSUJI Taiichi**
R04/A06	Electron transport through single colloidal quantum dot coupled to nanogap metal electrodes	**SHIBATA Kenji** Department of Electrical and Electronic Engineering, Tohoku Institute of Technology	**OTSUKA Tomohiro**
R04/A07	Database and its machine learning for development of next generation electromagnetic noise suppressors	**MUROGA Sho** Graduate School of Engineering Science, Akita University	**ISHIYAMA Kazushi**
R04/A08	High Frequency Response of Submicron-Sized Magnetic Materials with Asymmetric Magnetic Vortex Structure	**KODA Tetsunori** General Education Division, National Institute of Technology, Oshima College	**ISHIYAMA Kazushi**
R04/A09	Fabrication of spintronic devices based on antiperovskite-type metallic films with light elements	**ISOGAMI Shinji** Research Center for Magnetic and Spintronic Materials, National Institute for Materials Science	**SHIRAI Masafumi**
R04/A10	Japan-USA International Collaborative Research on the Theoretical and Experimental Investigation of Coulomb Drag Instability of Graphene Dirac Plasmons and its Application for THz Laser Transistors	**MITIN Vladimir** Department of Electrical Engineering, School of Engineering and Appl. Science, University at Buffalo, The State University of New York	**OTSUJI Taiichi**
R04/A11	Development of diamond RF high power devices and circuits for post-5G base station	**KANEKO Junichi** Graduate School Faculty of Engineering, Hokkaido University	**SUEMATSU Noriharu**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R04/A12	Manipulation of sense of self using multisensory information	**TANAKA Akihiro** Department of Psychology, Tokyo Woman's Christian University	**SAKAMOTO Shuichi**
R04/A13	Exploring and designing interactions for VR headsets using smartphone interfaces	**BOUSTILA Sabah** School of Digital Art, Manchester Metropolitan University	**TAKASHIMA Kazuki**
R04/A14	Online-based visual psychophysics and shared modeling environment	**SAKAI Ko** Faculty of Engineering Information and Systems, Tsukbua University	**SHIOIRI Satoshi**
R04/A15	Estimation of attention states during learning	**SHIOIRI Satoshi** Research Institute of Electrical Communication, Tohoku University	**SHIOIRI Satoshi**
R04/A16	Study on application of facial expression analysis to remote medical care	**SATO Yoshiyuki** Advanced Institute for Yotta Informatics, Tohoku University	**SHIOIRI Satoshi**
R04/A17	Creation, manipulation, and electrical control of chiral spin textures in non-collinear antiferromagnetic heterostructures	**TRETIAKOV Oleg** School of Physics, University of New South Wales	**FUKAMI Shunsuke**
R04/A18	Development of electrochemiluminescence microscopy for visualization of active biointerfaces	**HIRAMOTO Kaoru** Frontier Research Institute for Interdisciplinary Sciences, Tohoku University	**HIRANO Ayumi**
R04/A19	Study of Superconducting Nanowire for Single Photon Detection	**MIMA Satoru** Kobe Frontier Research Center, Advanced ICT Research Institute, National Institute of Information and Communications Technology	**SATO Shigeo**
R04/A20	Interpersonal coordination of motor, cognitive and neurophysiological processes in joint activities	**CHENG Miao** **Research Institute of Electrical Communication,** **Tohoku University**	**CHENG Miao**
R04/A21	Propagation directivity of wireless body area network	**AKIMOTO Kohei** Department of Intelligent Mechatronics, Faculty of Systems, Akita Prefectural University	**SUEMATSU Noriharu**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R04/A22	An Exploratory Study to Build an Environment for Collaborative HyFlex Classes" Utilizing XR Technology"	**HAYASHI Masako** Institute for Excellence in Higher Education, Tohoku University	**KITAMURA Yoshifumi**
R02/B02	Coherent Communication and Measurement Systems Incorporating Lightwave and Microwave	**INOUE Takashi** Electronics and Photonics Research Institute, National Institute of Advanced Industrial Science and Technology	**HIROOKA Toshihiko**
R02/B03	Layerless Design of Future Wireless Communications and Its Applications	**ISHIBASHI Koji** Advanced Wireless and Communication Research Center, The University of Electro-Communications	**SUEMATSU Noriharu**
R02/B04	Research on Wireless Technologies for the Beyond-5G System	**KUKI Takao** School of Science and Engineering, Kokushikan University	**SUEMATSU Noriharu**
R02/B06	Spatial User Interface by Understanding Human's Physical and Spatial Behaviors	**YAMAMOTO Goshiro** Kyoto University Hospital, Kyoto University	**TAKASHIMA Kazuki**
R02/B07	Human / Social Sensing Infrastructure by Heterogeneous Data Fusion	**OKABE Yasuo** Academic Center for Computing and Media Studies, Kyoto University	**OTSUJI Taiichi**
R02/B11	Development for automation of crows' behavior control method using vocal communication	**TSUKAHARA Naoki** CrowLab Inc	**KITAMURA Yoshifumi**
R02/B12	International Research Collaboration of Brainware LSI and Its Emerging Technologies	**HANYU Takahiro** Research Institute of Electrical Communication, Tohoku University	**HANYU Takahiro**
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**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R03/B01	Development of new physical phenomena at interfaces brought on by electron spins, orbitals and multipoles	**MIURA Yoshio** Research center for magnetic and spintronic materials, National Institute for Materials Science	**SHIRAI Masafumi**
R03/B03	A method for modeling of intellectual productivity and computational intervention for productivity enhancement	**ITOH Yuichi** Department of Integrated Information Technology, Aoyama Gakuin University	**TAKASHIMA Kazuki**
R03/B04	Functionalization of oxide surfaces and its application to biosensor devices	**HIROSE Fumihiko** Graduate School of Science and Engineering, Yamagata University	**HIRANO Ayumi**
R03/B05	High-dimensional and spatiotemporal neurodynamics and its system applications	**HIROSE Akira** Graduate School of Engineering, Tokyo University	**SATO Shigeo**
R03/B06	Theory and implementation for control-less wireless power supply systems	**SEKIYA Hiroo** Graduate School of Engineering, Chiba University	**HORIO Yoshihiko**
R03/B07	A Study on Adaptive Workspaces in the After-Corona Era	**FUJITA Kazuyuki** Research Institute of Electrical Communication, Tohoku University	**FUJITA Kazuyuki**
R03/B08	A study of the Application of Evolutionary Computation to Machine Learning	**JINNO Kenya** Department of Intelligent Systems, Faculty of Information, Tokyo City University	**HORIO Yoshihiko**
R03/B09	Study of perceptual, motor, cognitive, and emotional human characteristics towards the understanding of the neural mechanisms of social behavior	**TSUTSUI Ken-Ichiro** Graduate School of Life Sciences, Tohoku University	**SHIOIRI Satoshi**
R03/B11	Mental imagery processing in people with aphantasia	**TAKAHASHI Junichi** Faculty of Human Development and Culture, Fuskushima University	**SAKAMOTO Shuichi**
R03/B12	Empirical Research on dic Ubiquitous Computing Systems	**ISHIDA Shigeru** School of Systems Information Science, Department of Media, Future University Hakodate	**HASEGAWA Go**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R04/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**
R04/B02	Emergence of novel spin dynamics in solids and its device applications	**KOHDA Makoto** Graduate School of Engineering, Tohoku university	**KANAI Shun**
R04/B03	Nanomaterial synthesis by using novel gas-phase processes and its applications to high-performance devices	**UCHIDA Giichiro** Faculty of Science and Technology, Meijo University	**SATO Shigeo**
R04/B04	Control and exploartion of functions of quantum materials towards device applications	**MATSUNO Jobu** Graduate School of Science, Osaka University	**FUKAMI Shunsuke**
R04/B05	Studies on Antenna Technologies and Electromagnetic Analysis Methods for Developing Core of The Next Generation Wireless Systems	**KONNO Keisuke** Graduate School of Engineering, Tohoku University	**SUEMATSU Noriharu**
R04/B06	Designing the Next Normal of Academic Conferences	**KITAMURA Yoshifumi** Research Institute of Electrical Communication, Tohoku University	**KITAMURA Yoshifumi**
R04/B07	Theory of object recognition in vision and audition	**KURIKI Ichiro** Graduate School of Science and Engineering, Saitama University	**SAKAMOTO Shuichi**
R04/B08	Workgroup on fundamental technologies and issues of surface unmanned vehicles for sustainable society	**SUEDA Koh** SENSEFOIL PTE.LTD.	**KITAMURA Yoshifumi**
R04/B09	Studies on Generative Technology for Enriched Multimedia	**SONODA Kotaro** School of Information and Data Sciences, Nagasaki University	**SAKAMOTO Shuichi**
R04/B10	Application study on microwave and laser SAR	**KOGI Yuichiro** Department of Engineering, Fukuoka Institute of Technology	**YASAKA Hiroshi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R04/B11	An Inter-personal Dimension of MA: Behavior, Physiology, and Engineering	**TSENG Chia-huei** Research Institute of Electrical Communication, Tohoku University	**TSENG Chia-huei**
R04/B12	Research of the fundamental technologies of edge computing and edge-assisted smart systems for smart city	**SHAO Xun** Division of Information and Communication Engineering, Kitami Institute of Technology	**HASEGAWA Go**
R04/B13	Graph Content Visualization Techniques and Navigation Interfaces for Indoor Maps	**FUJITA Kazuyuki** Research Institute of Electrical Communication, Tohoku University	**FUJITA Kazuyuki**
R02/S1	Establishment for innovative coherent wave technology and its applications	**AOKI Toru** Research Institute of Electronics, Shizuoka University	**YASAKA Hiroshi**
R03/SI01	In English: Human sciences with AI technologies	**Su-Ling Yeh** AI and Advanced Robotics Center, Institute Graduate School National Taiwan University	**SHIOIRI Satoshi**
R04/T01	**Electromagnetic-Wave Transmission Technologies Workshop** Electromagnetic- and light-wave transmission technologies toward Society 5.0	**YAMADA Hirohito** Graduate School of Engineering, Tohoku University	**KASAI Keisuke**
R04/T02	**Technical committee for acoustic engineering** Research presentation on basic and application of acoustics, speech, hearing and multimodal systems	**SAKAMOTO Shuichi** Research Institute of Electrical Communication, Tohoku University	**SAKAMOTO Shuichi**
R04/T03	**Tohoku Plasma Forum** Fundamentals and applications of non-equilibrium plasma phenomena	**KANEKO Toshiro** Graduate School of Engineering, Tohoku University	**HIRANO Ayumi**
R04/T04	**Special Interest Group on Computer Science** Foundation and Application of Information Science around Theoretical Computer Science	**SUMII Eijiro** Graduate School of Information Sciences, Tohoku University	**NAKANO Keisuke**
R04/T05	**Technical committee for system control** Research presentation on theory and applications of system control	**WATANABE Takashi** Graduate School of Biomedical Engineering, Tohoku University	**ISHIGURO Akio**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R04/T06	**Research presentation on theory and applications of system control** Next generation biodevices based on bio-nanoelectronics	**HIRANO Ayumi** Research Institute of Electrical Communication, Tohoku University	**HIRANO Ayumi**
R04/T07	**Spinics Research Society** Development of Magnetic Materials and Their Magnetic Applications	**YABUKAMI Shin** Graduate School of Biomedical Engineering, Tohoku University	**ISHIYAMA Kazushi**
R04/T08	**New Paradigm Computing Research Group** Research and development of new paradigm computing technologies for the next generation IoT society	**HARIYAMA Masanori** Graduate School of Information Sciences, Tohoku University	**NATSUI Masanori**
R04/T09	**Technical committee for ultrasonic electronics** Research presentation on basics and applications of ultrasound	**KANAI Hiroshi** Graduate School of Engineering, Tohoku University	**SAKAMOTO Shuichi**
R04/T10	**Brainware Research Project** Toward Life-like Intelligent Information Processing System	**ISHIGURO Akio** Research Institute of Electrical Communication, Tohoku University	**ISHIGURO Akio**
R04/T11	**Biocybernetics and Bioinformatics** Analysis and modelling of biological signals	**SHIOIRI Satoshi** Research Institute of Electrical Communication, Tohoku University	**HATORI Yasuhiro**
R04/T12	**Study Group on Nanoelectronics and Spintronics** Next-generation information and communication technology based on nanoelectronics and spintronics	**SATO Shigeo** Research Institute of Electrical Communication, Tohoku University	**FUKAMI Shunsuke**

5. Symposium organized by the Institute

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

International symposium organized by the Institute (Symposiums held in FY2022)

No	Title	Date
118	2022 Spintronics Workshop on LSI	Jun. 13,2022
119	11th International Conference on Reactive Plasmas / 75th Annual Gaseous Electronics Conference	Oct. 3-7,2022
120	RIEC International Symposium on Human-Computer Interaction 2023	Feb. 17-18,2023
121	The 11th RIEC International Symposium on Brain Functions and Brain Computer	Feb. 17-18,2023
122	The 13th International Workshop on Nanostructures and Nanoelectronics	Mar. 7-8,2023
123	8th CIES Technology Forum	Mar. 27-28,2023
124	19th RIEC International Workshop on Spintronics (2nd Online RIEC International Workshop on Spintronics)	Mar. 14- Apr. 6,2023

6. 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.)
- The University of Sydney (Australia)
- Purdue University (U.S.A.)
- National Taiwan University (Taiwan)
- Swiss Federal Institute of Technology, Lausanne (Swiss)
- The University of York (U.K.)
- National Yang Ming 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)
- King Mongkut's University of Technology Thonbur (Taiwan)
- 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)
- Polish Academy of Sciences (Poland)
- 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)
- Telecom Paris Tech (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	IEEE Transactions on Circuits and Systems I
2	Journal of Multiple-Valued Logic and Soft Computing
3	Nonlinear Theory and Its Applications, IEICE
4	Frontiers in Physics
5	The Journal of Computer Animation and Virtual Worlds
6	Frontiers in Psychology
7	Frontiers in Neuroscience
8	Auditory Perception & Cognition

Recent international conferences programmed by a staff in RIEC

1	12th International Workshop on Nanostructures & Nanoelectronics (IWNN-12)
2	IEEE Inernational Symposium on Circuits and Systems (ISCAS 2021)
3	30th International Workshop on Post-Binary ULSI Systems (ULSIWS 2021)
4	16th ACM/IEEE International Symposium on Nanoscale Architectures (NANOARCH 2021)
5	2021 IEEE International Symposium on Multiple-Valued Logic (ISMVL 2021)
6	The 9th Russia-Japan-USA-Europe Symposium on Fundamental & Applied Problems of Terahertz Devices & Technologies (RJUSE TeraTech-2021)
7	International Symposium on Future Trends of Terahertz Semiconductor Technologies 2022 (TST2022)
8	2021 Nonlinear Science Workshop (NLSW2021)
9	Magnetics and optics research International symposium
10	Soft Magnetic Materials (SMM)
11	ACM International Symposium on Virtual Reality Software and Technoglogy (VRST 2021)
12	ACM International Symposium on Interactive Surfaces and Spaces (ISS 2021)
13	The 46th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz 2021)
14	The 11th International Conference on Metamaterials, Photonic Crystals and Plasmonics (META2021)
15	XXIV International Symposium on Nanophysics and Nanoelectronics
16	The 6th International Conference on Power and Renewable Energy (ICPRE 2021)
17	The International Conference on Micro- and Nanoelectronics 2021 (ICMNE 2021)
18	The 12th Recent Progress in Graphene and Two-Dimensional Materials Research Conference (RPGR 2021)
19	The 5th Graphene Flagship Japan-EU Workshop on Graphene and Related 2D Materials
20	SPIE Photonics West 2022 International Symposium, Conference 11975 on Advances in Terahertz Biomedical Imaging and Spectroscopy
21	XXVI International Symposium on Nanophysics and Nanoelectronics
22	SPIE Photonics Europe 2022 International Symposium
23	ACM International Symposium on Virtual Reality Software and Technoglogy (VRST) Steering Committee Chair
24	ACM Conference on Human Factors in Computing Systems (CHI 2021) General Chair

7. 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 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/

8. Staff, Budget

1. Faculty & Staff

as of May 1, 2022

Professors	20
Associate Professors	19
Assistant Professors	20
Research Fellows	4
Specially Appointed Professors	2
Specially Appointed Assistant Professors	4
Administrative Staff（Including Limited Regular Employees）	30
Technical Staff（Including Limited Regular Employees）	15
Total	114

2. Researchers (FY2022)

Foreign Researchers	Visiting Professors	2
	Visiting Asociate Professors	1
Cooperative Researchers of Private Company etc		9
JSPS Research Fellowship for Young Scientists		6
JSPS Postdoctral Fellowship for Overseas Researchers		3
Invitation Fellowship for Research in Japan		1
Contract Researchers		1
Contract Trainees		1
Total		24

3. Students

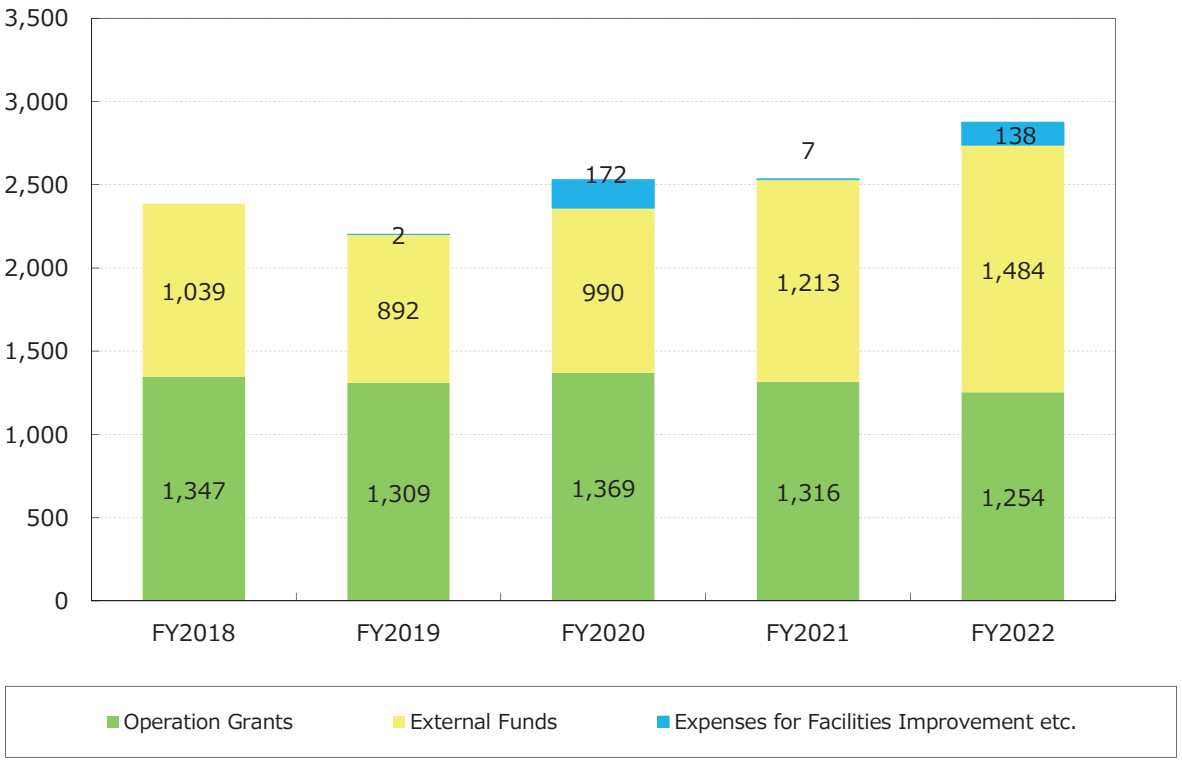
as of May 1, 2022

	School of Engineering	Graduate School of Information Science	Graduate School of Biomedical Engineering	RIEC	Total
Undergraduate Students	56 (1)				56 (1)
Master Course Students	98 (4)	46 (9)	2		146 (13)
Doctor Course Students	13 (10)	10 (5)	5		28 (15)
Institute Reserch Students				4 (2)	4 (2)
Total	167 (15)	56 (14)	7	4 (2)	234 (31)

4. Budget

Budget Shift

million yen



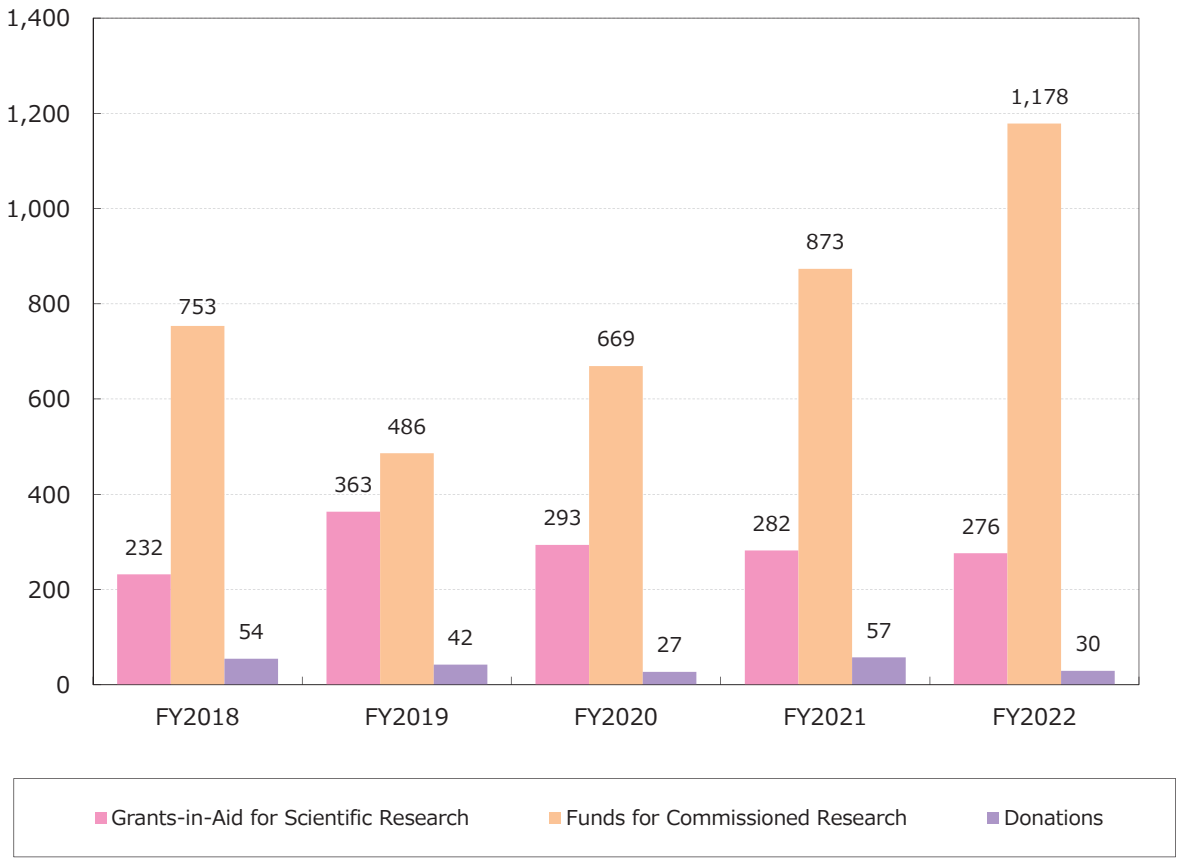
■ Budget Summary

thousand yen

Categories		FY2018	FY2019	FY2020	FY2021	FY2022
Operation Grants	Personnel Expenses	790,118	742,128	801,695	744,591	699,851
	Non-Personnel Expenses	556,937	566,533	567,249	571,737	553,851
Operation Grants Total		1,347,055	1,308,661	1,368,944	1,316,328	1,253,702
External Funds	Grants-in-Aid for Scientific Research	231,643	363,325	293,404	282,400	276,146
	Funds for Commissioned Research	753,391	486,053	669,454	873,456	1,178,325
	Donations	54,344	42,436	27,200	57,422	29,604
	Indirect Expenses	134,311	155,852	172,874	234,487	315,346
External Funds Total		1,039,378	891,814	990,058	1,213,278	1,484,075
Expenses for Reconstruction		0	1,936	172,477	6,732	20,472
Expenses for Relocation		0	0	0	0	0
Expenses for Facilities Improvement		0	0	0	0	117,997
Expenses for Facilities Improvement etc. Total		0	1,936	172,477	6,732	138,469
Total		2,386,433	2,202,411	2,531,479	2,536,338	2,876,246

External Funds

million yen



■ External Funds

thousand yen

Categories	FY2018	FY2019	FY2020	FY2021	FY2022
Grants-in-Aid for Scientific Research	231,643	363,325	293,404	282,400	276,146
Funds for Commissioned Research	753,391	486,053	669,454	873,456	1,178,325
Donations	54,344	42,436	27,200	57,422	29,604
Total	1,039,378	891,814	990,058	1,213,278	1,484,075

Annual Report 2022

Research Institute of Electrical Communication
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