Annual Report 2023

Research Institute of Electrical Communication
Tohoku University

Annual report of Research Institute of Electrical Communication 2023

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, the first Co-Creation Research Institute, which promotes industry-academia collaboration, has been established in April 2023 (during three tears), and the "Research Center for Comprehensive Knowledge Informatics" has been newly established in fiscal year 2024, led by the members of the institute, following the Ministry of Education, Culture, Sports, Science and Technology (MEXT) for budgetary allocation. We also 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.

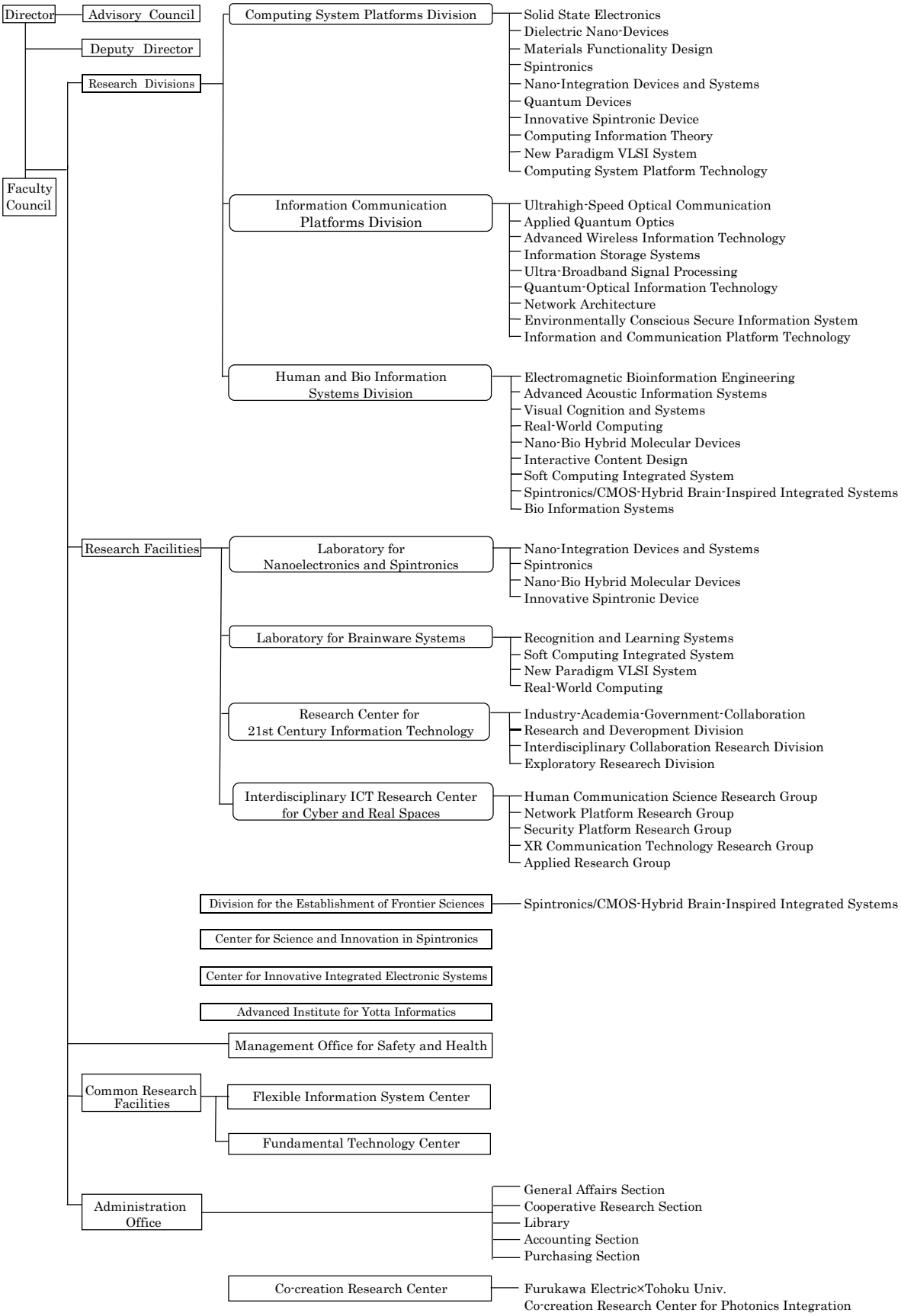
To contribute to the improvement of our research activities and support future developments, we publish this Annual Report every year to make our activities relating to research, education, and social contribution widely available for public scrutiny. This edition contains reports on a range of activities,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

2024

Takahiro Hanyu
Director, Research Institute of Electrical Communication

2. Organization Chart



3. Research Activities

Targets and achievements of the Computing System Platform Division

The computing system platform division is conducting research by vertically integrating the scientific areas ranging from condensed-matter physics and material science to devices, processes, circuits, systems, and software, in order to acquire the "Transcendent Computational Capability" that is one of the three major challenges in the "RIEC Future Vision" set in 2021. The research being conducted in this division will lead to the construction of technology to address computationally hard problems with high speed and low energy, which are difficult for the conventional computing scheme to efficiently address. To this end, we conduct research to establish fundamental understanding for designing devices, circuits, and software as well as to develop new-functional information devices and systems. We aim to realize semiconductor/ dielectric/ quantum/ and spintronic devices that utilize new functionalities emerged in novel materials and nanostructures, new-paradigm semiconductor circuits based on unconventional design principles and devices, and highly dependable programming languages.

To achieve the goal, the following 11 laboratories are carrying out research and developments.

1. Solid State Electronics
2. Dielectric Nano-Devices
3. Materials Functionality Design
4. Spintronics
5. Nano-Integration Devices and Systems
6. Quantum Devices
7. Innovative Spintronic Device
8. Computing Information Theory
9. New Paradigm VLSI System
10. Software Construction
11. Computing System Platform (Visitor Section)

The research target and the summary of activities of each sub-division in FY2023 are described in the following pages.

Solid State Electronics Laboratory

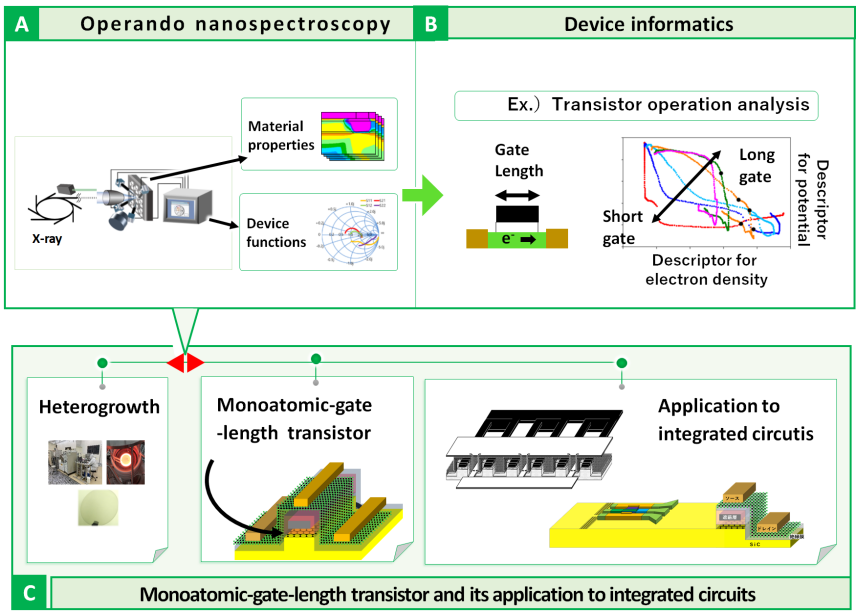
Creation of the ultimate transistor and its application to integrated circuits

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 2023, we succeeded for the first time in fabricating the gate stack structure consisting of atomically thin channel and atomically-shortened gate by orthogonally growing graphene and 2D semiconductors. This fabrication was published as two patents. Furthermore, we exploited the white-box DI using the expanded free-energy model visualized in cyber space.



The summary of our work.

[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] H. Fukidome, Issei Watanabe, M. Kawahara, M. Akiyama, M. Kawai, "Transistor, integrated circutis, and the process to fabricate transistor", Japan Patent Application No. 2023-095711, 2023.6.9.
[2] H. Fukidome, T. Suemitsu, I. Watanabe, M. Kawahara, M. Akiyama, M. Kawai, "Transistor integrated circutis, and their fabricate processes", Japan Patent Application No. 2023-095712, 2023.6.9.

Contact to Associate Professor FUKIDOME Hirokazu : hirokazu.fukidome.e7@tohoku.ac.jp

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.

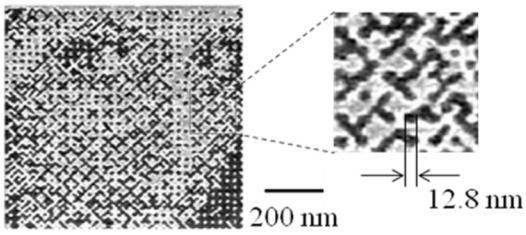


Fig.1 Digital bit data written on ferroelectric single crystal with the areal recording density of 4 Tbit/inch^2.

Major achievements of studies in 2023 are as follows: (1) The impact of grain boundaries on the polarization switching behavior of hafnium oxide-based ferroelectric thin films was quantitatively evaluated. This was done by directly comparing the mapping data of polarization switching behavior obtained by local C-V mapping with grain boundary patterns extracted from surface topography images in real space. (2) We performed nanoscale evaluation of wide-bandgap semiconductors, such as GaN and diamond, and atomic-layer semiconductors using local capacitance-voltage profiling based on time-resolved SNDM. We also developed a device simulator that enables the evaluation of the impact of spatially fluctuating interface charges on the electrical characteristics of power MOSFETs.

[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 *et al.*, The 43th Annual NANO Testing Symposium (NANOTS2023), pp. 26-30 (2023).
[2] Yoshiomi Hiranaga, "Visualization of Nanoscale Ferroelectric Domain Dynamics Based on Local Capacitance Measurements", JAIST International symposium of Nano-Materials for Novel Devices, January 12, 2024 [invited]

Materials Functionality Design

Computational Design of Materials and their Functionalities 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 2023 are as follows:

(1) Design of magnetic tunnel junctions (MTJs) with the aid of machine learning

We explored MTJs, which are robust against thermal fluctuation of magnetic moments at the interface, by using ab initio calculations with the aid of machine learning. As a result, we found that CoCrMnZ/MgO (Z = Al, Ga, Si, Ge) interfaces (see Fig. 1) have large exchange stiffness and thus CoCrMnZ are promising candidates as electrode materials of the MTJs [1, 2].

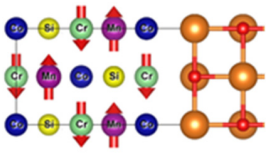


Fig. 1

(2) *Ab initio* study of structures in dense atomic hydriogen

The phase diagram of atomic hydrogen at terapascal pressures is investigated by using *ab initio* methods, where two exchange-correlation functionals are compared: the generalized gradient approximation (GGA) and the van der Waals density functional (vdW-DF). The effects of proton zero-point energy on structures are also examined, anharmonicity being considered with the use of the self-consistent harmonic approximation. The analysis shows that the transition into an isotropic phase takes place at 3.5 TPa in the GGA and 4.6 TPa in the vdW-DF. The findings suggest that the choice of the functional form is still crucial to the prediction of the phase diagram of hydrogen at terapascal pressures.

[Staff]

Professor: Masafumi Shirai, Dr.
Associate Professor: Kazutaka Abe, Dr.
Assistant Professor: Masahito Tsujikawa, 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] R. Okabe, M. Li, Y. Iwasaki, N. Refnault, C. Felser, M. Shirai, A. Kovacs, T. Schrefl and A. Hirohata, “Materials informatics for the development and discovery of future magnetic materials,” IEEE Magn. Lett., Vol. 14, pp. 2500305/1-5, 2023

[2] T. Roy, M. Tsujikawa and M. Shirai, “Ballistic spin-transport properties of magnetic tunnel junctions with MnCr-based ferromagnetic quaternary Heusler alloys,” Phys. Rev. Mater., Vol. 7, pp. 104410/1-11, 2023

Contact to Professor SHIRAI Masafumi : masafumi.shirai.b8@tohoku.ac.jp

Spintronics

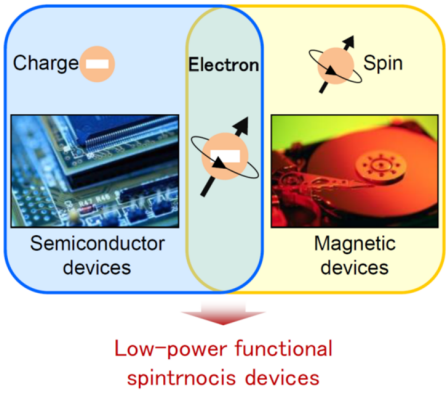
Advanced technology for spintronics-based devices

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 electron and its spin states are controlled. We are also working on research and development of advanced technology for spintronics-based devices and unconventional computing, which offer high-performance and low-power information and communication tecnologies.

The outcomes in the last fiscal year include (1) discovery of fundamental difference between magnetic octupole and dipole in their response to spin torque, (2) establishment of basic understanding to tailor single-nanometer magnetic tunnel junction for various MRAM applications, and (3) proposal and demonstration of energy-efficient and easy-to-manufacture probabilistic computer with CMOS and stochastic nanomagnet.



[Staff]

Professor: Shunsuke Fukami, Ph. D., Associate Professor: Shun Kanai, 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 Tohoku 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] J.-Y. Yoon, P. Zhang, C.-T. Chou, Y. Takeuchi, T. Uchimura, J. T. Hou, J. Han, S. Kanai, H. Ohno, S. Fukami, and L. Liu, "Handedness anomaly in a non-collinear antiferromagnet under spin–orbit torque," Nature Materials 22, 1106–1113 (2023). doi:10.1038/s41563-023-01620-2

[2] J. Igarashi, B. Jinnai, K. Watanabe, T. Shinoda, T. Funatsu, H. Sato, S. Fukami, and H. Ohno, "Single-nanometer CoFeB/MgO magnetic tunnel junctions with high-retention and high-speed capabilities," npj Spintronics 2, 1(1)-(9) (2024). doi:10.1038/s44306-023-00003-2

[3] N. S. Singh, K. Kobayashi, Q. Cao, K. Selcuk, T. Hu, S. Niazi, N. A. Aadit, S. Kanai, H. Ohno, S. Fukami, and K. Y. Camsari, "CMOS plus stochastic nanomagnets enabling heterogeneous computers for probabilistic inference and learning," Nature Communications 15, 2685(1)-(9) (2024). doi:10.1038/s41467-024-46645-6

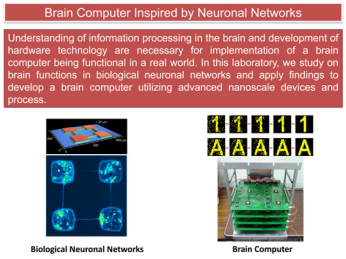
Nano-Integration Devices and Systems

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 reservoir computing system has been configured using a spiking neural network LSI that reproduces various neural pulses and operates at extremely low power. Electrical measurements confirmed that the system could correctly classify data such as voice and handwritten text at low power. (2) To develop Esaki diode, heavily P-doped Si film deposition with a carrier concentration of $2x10^{20}$ cm^{-3} was realized by using ECR plasma CVD. Moreover, we developed a pn junction diode fabrication process using wet etching of the P-doped Si, and confirmed good rectifying characteristics. (3) We showed that micropatterned neuronal networks can be integrated in the reservoir computing paradigm to study the computational advantages of non-random network organizations.



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] J. Madrenas, B. Vallejo-Mancero, J. À. Oltra-Oltra, M. Zapata, J. Cosp-Vilella, R. Calatayud, S. Moriya, S. Sato, "Real-time adaptive physical sensor processing with SNN hardware," 2023 International Conference on Artificial Neural Networks (ICANN), pp 423-434, 2023.

[2] T. Sumi, H. Yamamoto, Y. Katori, K. Ito, S. Moriya, T. Konno, S. Sato, A. Hirano-Iwata, "Biological neurons act as generalization filters in reservoir computing," Proceedings of the National Academy of Sciences, U.S.A., 120, e2217008120, 2023.

Contact to Professor SATO Shigeo : shigeo.sato.e3@tohoku.ac.jp

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 2023 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-speed electronics and developed techniques for new materials [1].

(2) Measurement of local electronic states in nanostructures

We measured local electronic and spin states in nanostructures using sensitive electronic measurement techniques. We revealed the local electronic states in nanostructures and new materials [2].

(3) Development of quantum devices and systems

We studied semiconductor quantum devices for future quantum information processing. We investigated state analysis and control of quantum devices, and developed techniques for scaling up the systems and creating new material-based devices [3].

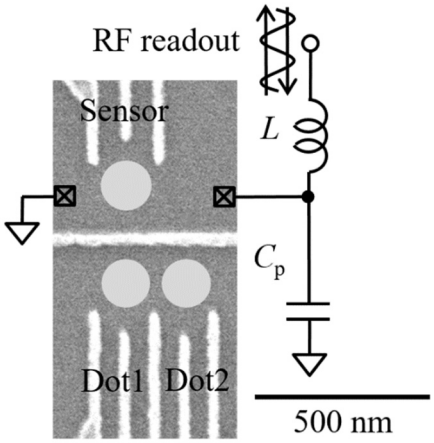


Figure: Scanning electron micrograph of a nanostructure device

[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, 2023).

[Papers]

[1] "Wide dynamic range charge sensor operation by high-speed feedback control of radio-frequency reflectometry", Y. Fujiwara, M. Shinozaki, K. Matsumura, K. Noro, R. Tataka, S. Sato, T. Kumasaka, and T. Otsuka, Applied Physics Letters 123, 213502 (2023).

[2] "Single PbS colloidal quantum dot transistors", K. Shibata, M. Yoshida, K. Hirakawa, T. Otsuka, S. Z. Bisri, and Y. Iwasa, Nature Communications 14, 7486 (2023).

[3] "Radio-frequency reflectometry in bilayer graphene devices utilizing micro graphite back-gates", T. Johmen, M. Shinozaki, Y. Fujiwara, T. Aizawa, and T. Otsuka, Physical Review Applied 20, 014035 (2023).

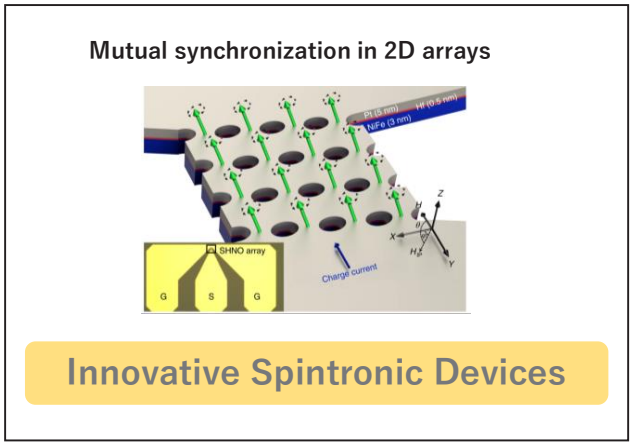
Innovative Spintronic Device

Magnetization dynamics-based innovative spintronic devices

Computing System Platforms Division: Johan Åkerman, Professor,
University Research Lead The Center for Science and Innovation in Spintronics (CSIS):
Ahmad Awad, Associate Professor

[Research Target and Activities]

In spintronic devices, the interaction between magnetization and current via electron spins is being investigated to apply it to unconventional computing such as neuromorphic computing and Ising machines. We are working on the oscillation of magnetization to DC input via the spin Hall effect and the associated output of RF signals, the realization of spin Hall nano-oscillators using magnetic resonance to RF input and the associated output of DC signals for higher performance and novel functionality, the formation of unexplored antiferromagnetic topological spin structures and their fast and efficient current-driven dynamics, etc.



[Staff]

Professor: Johan Åkerman
Associate Professor: Ahmad Awad（CSIS）
Assistant Professor: Takaaki Dohi

[Profile]

Johan Åkerman received the Ing. Phys. Dipl. degree from EPFL, Zurich, Switzerland, in 1994, the M.Sc. degree in physics from Lund University, Lund, Sweden, in 1996, and the Ph.D. degree in materials physics from KTH Royal Institute of Technology, Stockholm, Sweden, in 2000. In 2008, he was appointed Full Professor at the University of Gothenburg, Gothenburg, Sweden, and is a Guest Professor at the KTH Royal Institute of Technology. Also, he was appointed to a post at Tohoku University and - following an extensive nomination and review process - been named its first "Professor, University Research Lead" as of January 1, 2023. He is also the Founder of NanOsc AB and NanOsc Instruments AB, Kista, Sweden.

Ahmad A. Awad (Member, IEEE) received the Ph.D. degree in physics on high-frequency magnetization and vortex dynamics in both magnetic and superconducting nanostructures from the Autonomous University of Madrid, Madrid, Spain, in 2012., Since 2014, he has been a Postdoctoral Research Fellow at the University of Gothenburg, Gothenburg, Sweden. His research interests include the characterization of magnetic nanostructures and spintronic devices with a focus on spin-torque-induced magnetization dynamics. In 2023, he was appointed associate Professor at Tohoku University.

Contact to Professor AAKERMAN BENGT JOHAN : aakerman.bengt.johan.e3@tohoku.ac.jp

[Papers]

[1] Akash Kumar, Himanshu Fulara, Roman Khymyn, Mohammad Zahedinejad, Mona Rajabali, Xiaotian Zhao, Nilamani Behera, Afshin Houshang, Ahmad A Awad, and Johan Åkerman, "Robust mutual synchronization in long spin Hall nano-oscillator chains," Nano Letters 23, 6720-6726 (2023). doi.org/10.1021/acs.nanolett.3c02036

[2] Nilamani Behera, Avinash Kumar Chaurasiya, Victor H González, Artem Litvinenko, Lakhan Bainsla, Akash Kumar, Roman Khymyn, Ahmad A Awad, Himanshu Fulara, and Johan Åkerman, "Ultra - Low Current 10 nm Spin Hall Nano - Oscillators," Advanced Materials 36, 2305002(1)–(9) (2024). doi/10.1002/adma.202305002

[3] Takaaki Dohi, Markus Weißenhofer, Nico Kerber, Fabian Kammerbauer, Yuqing Ge, Klaus Raab, Jakub Zázvorka, Maria-Andromachi Syskaki, Aga Shahee, Moritz Ruhwedel, Tobias Böttcher, Philipp Pirro, Gerhard Jakob, Ulrich Nowak, and Mathias Kläui, " Enhanced thermally-activated skyrmion diffusion with tunable effective gyrotropic force," Nature Communications 14, 5424(1)-(10) (2023). doi.org/10.1038/s41467-023-40720-0

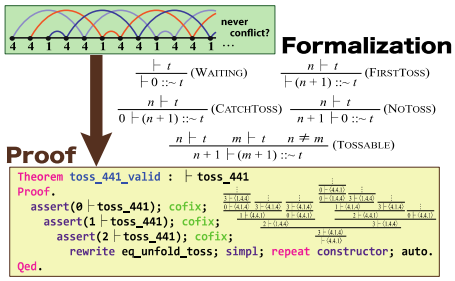
[4] Mona Bhukta, Takaaki Dohi, Venkata Krishna Bharadwaj, Ricardo Zarzuela, Maria-Andromachi Syskaki, Michael Foerster, Miguel Angel Niño, Jairo Sinova, Robert Frömter, and Mathias Kläui, "Homochiral antiferromagnetic merons, antimerons and bimerons realized in synthetic antiferromagnets," Nature Communications 15, 1641(1)–(10) (2024). doi.org/10.1038/s41467-024-45375-z

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] Keishi Hashiba, Keisuke Nakano, Kazuyuki Asada,Kentaro Kikuchi.In Proc. the 26th Workshop on Programming and Programming Languages (PPL 2024).
[2] Takeshi Tsukada and Kazuyuki Asada,Enriched Presheaf Model of Quantum FPC, Proc. ACM Program. Lang., January 2024, Volume 8, Issue POPL, Article No. 13, pp. 362-392.
[3] K Kazuki Watanabe, Clovis Eberhart, Kazuyuki Asada, and Ichiro Hasuo. Compositional Probabilistic Model Checking with String Diagrams of MDPs, In Proc. the 35th International Conference on Computer Aided Verification (CAV 2023), LNCS 13966, pp. 40-61.

Contact to Professor NAKANO Keisuke : keisuke.nakano.a3@tohoku.ac.jp

New Paradigm VLSI System Research Group

Realization of a New-Paradigm VLSI-Computing World

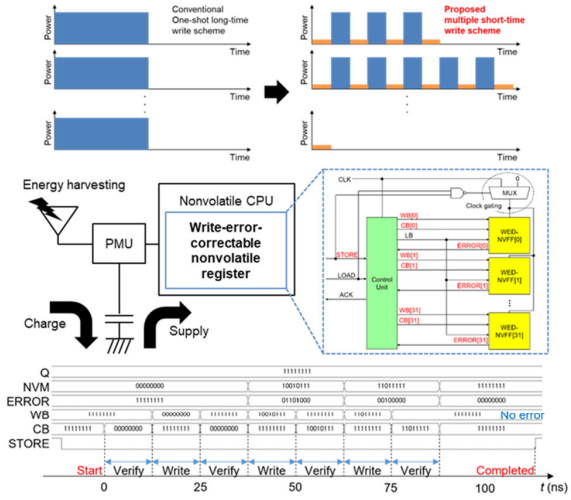


Fig. 1. Nonvolatile register based on a new data write scheme that suppresses the energy required for data retention in intermittent computing.

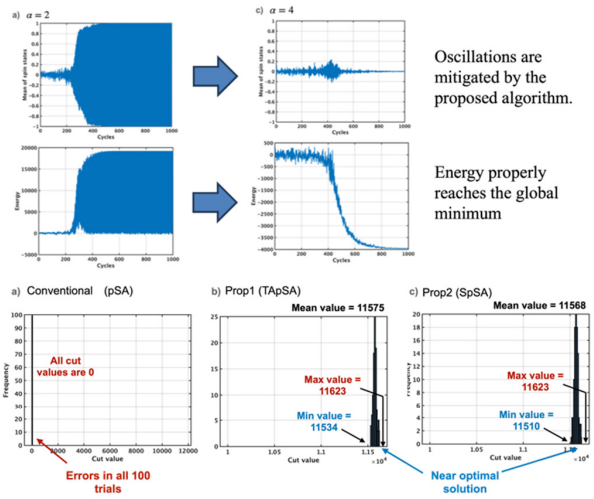


Fig. 2. The development of a parallel probabilistic algorithm has successfully enabled stable and optimal solutions in probabilistic computers.

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 an MTJ-based nonvolatile register based on a new data write scheme for intermittent computing (Fig. 1), and the parallel probabilistic algorithm that has successfully enabled stable and optimal solutions in probabilistic computers (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 and T. Hanyu, "Enhanced Convergence in p-bit Based Simulated Annealing for Large Scale Combinatorial Optimization Problems," Scientific Reports, vol. 14, p. 1339, 2024. DOI: 10.1038/s41598-024-51639-x
[2] N. Onizawa, K. Kuroki, D. Shin, and T. Hanyu, "Local Energy Distribution Based Hyperparameter Determination for Stochastic Simulated Annealing," IEEE Open Journal of Signal Processing, vol. 4, pp. 452-461, 2023. DOI: 10.1109/OJSP.2023.3329756
[3] K. Sakai, M. Natsui, and T. Hanyu, "Design of an Error-Tolerant Nonvolatile Register for Energy-Aware Intermittent Computing," The 66th IEEE International Midwest Symposium on Circuits and Systems (MWSCAS2023), pp.269-273, August 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).

Information Communication Platforms Division: Research Targets and Results

This division aims to research and develop ultra-high-speed, high-performance, ultra-low-power optical/high-frequency devices and secure, resilient, and green broadband ICT infrastructure to create next-generation information communication systems that support a sustainable smart society. The following is an overview of the research activities of the core laboratories in this academic year.

(1) Ultrahigh-Speed Optical Communication
We are engaged in research on ultrahigh-speed optical transmission, digital coherent transmission, and high-speed and spectrally efficient optical transmission by combining these two approaches. With a view to supporting innovative new ICT services such as 5G and IoT, our goal is also to develop novel transmission schemes integrating optical and wireless communications. This year, we successfully demonstrated 1 Tbit/s/λ x 23 ch OTDM-WDM transmission over 1,600 km by newly introducing Probabilistically Shaped (PS)-QAM formats to coherent optical Nyquist pulses. We also applied our coherently-linked optical and wireless transmission scheme to a 28 GHz band and successfully demonstrated a 16 Gbit/s, 256 QAM transmission over a 10 km fiber and 20 m wirelessly by using a microstrip antenna.

(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 an ultra-high-speed semiconductor laser introducing hybrid modulation scheme was being continued. It was confirmed numerically that the hybrid modulation laser can control the frequency chirp and increase the dispersion tolerance in single mode optical fiber transmission. And it was also confirmed numerically that a hybrid modulation semiconductor laser integrated with a passive waveguide has wide modulation bandwidth more than 200 GHz even under the condition that the load resistance is 50 Ω thanks to the optical pre-emphasis of the modulation response by the photon-photon resonance effect. Furthermore the study on a compact and narrow linewidth optical negative feedback laser was also continued. It was confirmed experimentally that the optical frequency of the optical negative feedback laser is able to sweep 10 GHz by synchronizing the resonant frequency of the optical filter to the lasing light.

(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 invented novel scalable millimeter-wave band DBF antenna and transceiver for LEO constellation satellites.

(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 recording performance of heat-assisted magnetic recording (HAMR), with the aim of doubling the storage capacity. We have also been studying arrays of spintronic devices (spin-torque-oscillators) for use in artificial neural networks. We have demonstrated data transmission and data path selection in 2-dimentiomal STO arrays. We have completed 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 utilizing compound semiconductor heterostructure and graphene-based 2D materials.
First, we have theoretically discovered new instability mechanisms originating from the Coulomb drag effect of graphene Dirac plasmons and the Zener-Klein tunneling effect of graphene Dirac fermions, and revealed their exceptional giant terahertz gain bandwidth properties. Second, regarding InGaAs high-electron-mobility-transistor-based terahertz plasmonic detectors with original metallic diffraction-grating structures, we demonstrated that the "3D rectification effect", where the diode current nonlinearity associated with the electron tunneling is superimposed onto the plasmonic hydrodynamic nonlinearities, can take place by applying a forward gate bias voltage and succeeded in drastic enhancement of the detector responsivity by one order of magnitude (press released on Nov. 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 2023, we have achieved (1) development of plasmon-enhanced single photon source coupled to an optical nanofiber, (2) optical trapping and transport of nanoparticles on an optical nanofiber, (3) development of ultra-low-loss, polarization-maintaining photon switch, (4) generation of ultrapure heralded single photons via controlled quasi-phase-matched parametric down-conversion, and (5) evaluation of error-disturbance uncertainty relation using small-scale superconducting quantum computer.

(7) Network Architecture
We have promoted research on information network systems and their applications that support diverse human activities. (1) We proposed an in-network congestion control architecture that fundamentally overturns conventional concepts and clarified its potential performance through performance analysis. (2) We developed an improved method to maintain fairness in the unavoidable situation of mixed congestion control algorithms in the Internet (3) We developed a traffic compression technique for remote management of network devices using LPWA networks. (4) We clarified the relationship between the introduction of edge computing technologies and the improvement of wireless network resource utilization efficiency, and established a machine learning-based edge utilization decision method.

(8) Environmentally Conscious Secure Information System
We are conducting research and development on the theories and implementation technologies of secure information communication systems. This year, we succeeded in developing the world's most efficient physical security evaluation technology for quantum-resistant cryptography, which is attracting attention as a next-generation cryptography. We have also developed a new concept of key exchange technology that dramatically improves the physical security of cryptographic implementation.

Research Laboratory of Ultrahigh-Speed Optical Communication

Toward Innovative Optical Transmission from Backbone to Access Networks

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

[Research Target and Activities]

Advanced global ICT services such as ultrahigh-definition video transmission and ultra-realistic communication cannot be realized without high-speed and large-capacity optical transmission systems. At the same time, optical transmission schemes with high spectral efficiency are crucial in terms of the maximum utilization of limited bandwidth resources. In our laboratory, we are engaged in research on ultrahigh-speed optical transmission using optical time division multiplexing with a single-channel Tbit/s-class capacity, digital coherent QAM optical transmission, and high-speed and spectrally efficient optical transmission by combining these two approaches. With a view to supporting innovative new ICT services such as 5G and IoT, our goal is also to apply digital coherent transmission to access networks and mobile fronthaul, and to develop novel transmission schemes integrating optical and wireless communications. This year, we introduced PS-QAM formats to coherent optical Nyquist pulses and demonstrated 1 Tbit/s/λ x 23 ch PS-32 QAM transmission over 1,600 km, resulting in long-distance (>1,000 km) transmission at 1 Tbit/s/λ for the first time.

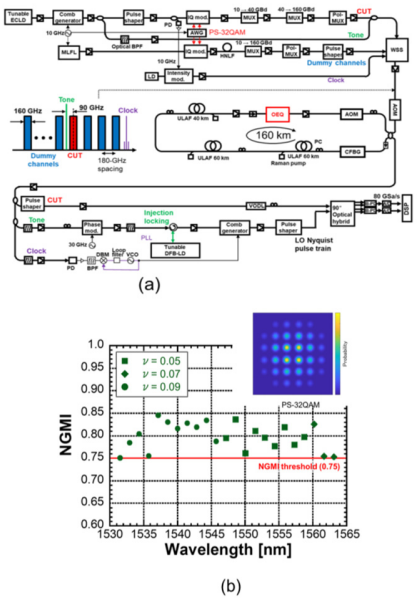


Fig. 1. 1 Tbit/s/λ PS-32 QAM coherent Nyquist pulse transmission over 1,600 km. (a) Experimental setup, (b) transmission results.

[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] M. Yoshida, K. Kimura, T. Hirooka, K. Kasai, and M. Nakazawa, “Demodulation performance comparison of high-speed coherent Nyquist pulse signal with analog and digital demultiplexing schemes,” IEICE Trans. Commun. vol. E106-B, no. 11, pp. 1059-1064, November (2023).
[2] M. Nakazawa, M. Yoshida, and T. Hirooka, "Eigen-function division multiplexed coherent optical transmission in time domain by using higher-order Hermite-Gaussian pulses," Opt. Express, vol. 32, no. 7, pp. 12682-12707, March (2024).
[3] K. Shirahata, K. Kasai, T. Hirooka, M. Yoshida, M. Nakazawa, U. Azuma, and T. Kobayashi, “16 Gbit/s, 256 QAM optical and wireless fully coherent transmission at 28 GHz using small microstrip antenna,” ECOC 2023, Tu.B.4.1, October (2023).

Contact to Professor HIROOKA Toshihiko : toshihiko.hirooka.a8@tohoku.ac.jp

Applied Quantum Optics

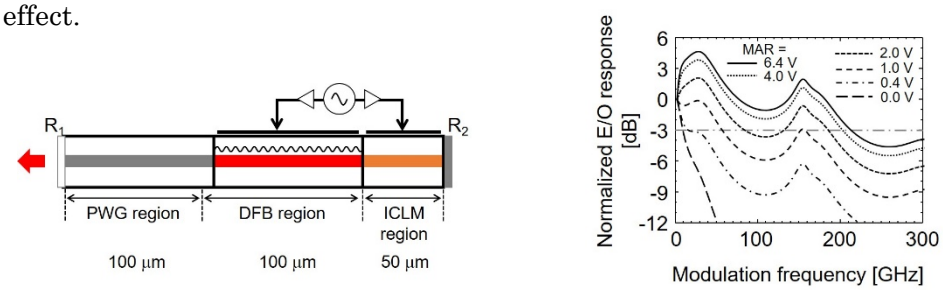
Research on Innovative Highly Functional Photonic Semiconductor Devices

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 numerically that a hybrid modulation semiconductor laser integrated with a passive waveguide has wide modulation bandwidth more than 200 GHz even under the condition that the load resistance is 50 Ω thanks to the optical pre-emphasis of the modulation response by the photon-photon resonance effect.



Schematic structure of a hybrid modulation laser integrated with a passive waveguide (left) and its 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] S. Asami, N. Yokota, W. Kobayashi, T. Shindo, and H. Yasaka, "Numerical analysis of negative chirp operation in hybrid modulation semiconductor laser," IEICE Electronics Express, vol. 20, No. 17, pp. 20230268 1-5, 2023.
[2] H. Yasaka, N. Yokota, T. Shindo, and W. Kobayashi, "Improvement in bandwidth of an electro-absorption modulator by optical pre-emphasis utilizing photon-photon resonance," IEICE Electronics Express, vol. 21, No. 2, pp. 20230594 1-4, 2024.

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.

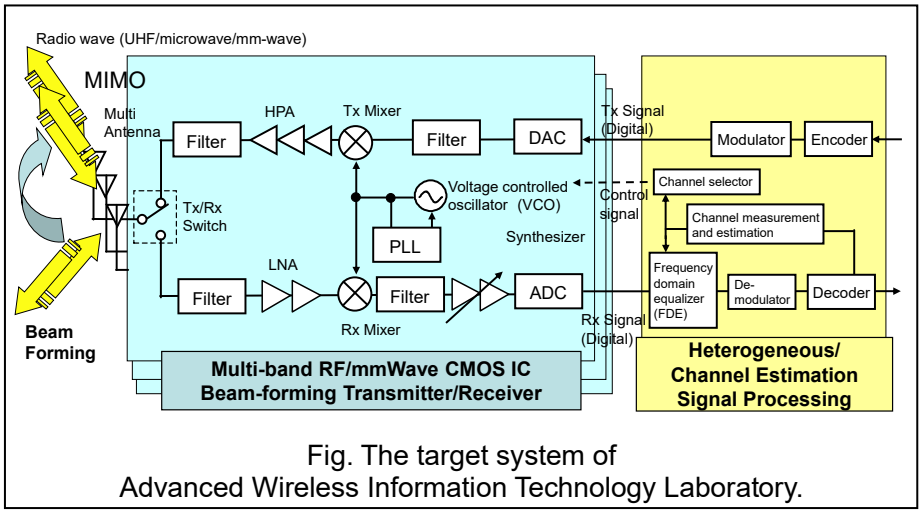


Fig. The target system of Advanced Wireless Information Technology Laboratory.

This year, we have successfully developed a millimeter-wave direct digital RF transmitter architecture which consist of Manchester coder and RF tripler. We have also developed sub-THz band on-chip antenna and RFIC, both fabricated in CMOS process.

[Staff]

Professor: Noriharu Suematsu, Ph. D
Assistant Professor: Tomoyuki Furuichi, Ph.D
Research Fellow: Ahmad Abdalrazik, Ph.D
Junhao Zhang、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] Junhao Zhang, Noriharu Suematsu, “Image Enhancement Technique Using Manchester Coding and RF Tripler for 1-bit Bandpass Delta Sigma Direct Digital RF Transmitter,” IEEE Access, pp. 73359 - 73369, Nov. 2023.
[2] Jean Temga, Mizuki Motoyoshi, Noriharu Suematsu, “Sub-Terahertz-Band On-Chip 2×2 Beam-Forming Array Antenna Using a Compact 2-D BFN On 45nm SOI CMOS,” 2023 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), pp. 63-66, Aug. 2023.
[3] Fumito Karasawa, Taiki Machii, Mizuki Motoyoshi, Tomoyuki Furuichi, Noriharu Suematsu, “130 GHz Band CMOS Amplifier with Miniaturized Interstage Circuit by Stacked Radial Stubs,” 2023 Asia-Pacific Microwave Conference (APMC), pp.769-771, Dec. 2023.
[4] Ahmad Abdalrazik, Noriharu Suematsu, "Wideband Half-Cross Shaped Slotted Patch Antenna For 5G Applications, " 2023 Asia-Pacific Microwave Conference (APMC), pp.688-690, Dec. 2023.

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

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, low-cost storage due to the rapid growth of the Internet and web services. We use computer simulations to study recording systems and novel technologies for data storage applications. 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 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 [1][2]. We have also been studying arrays of spintronic devices (spin-torque-oscillators) for use in artificial neural networks. We have demonstrated data transmission and data path selection in 2-dimensional STO arrays [3].

We have also completed 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].

[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 IEEE and the Japan Magnetic Society, as well as 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]

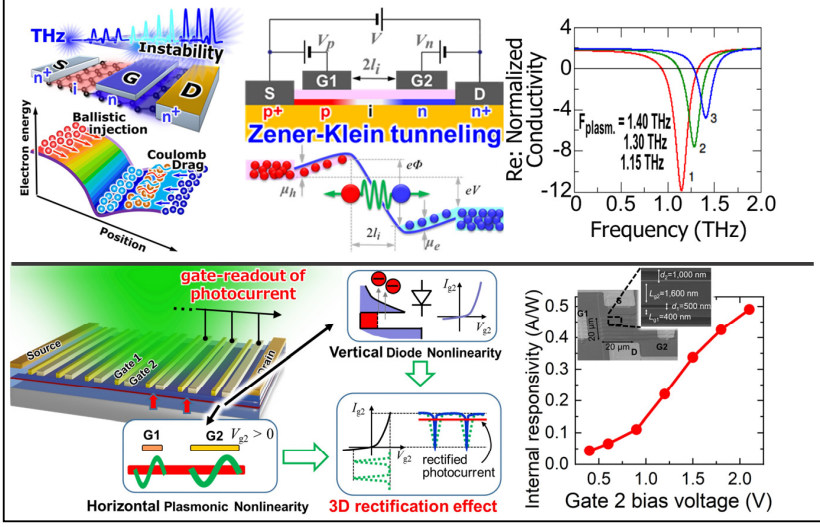
[1] S. J. Greaves, K. Tatsuno and Y. Kanai, “Write head design for control of transition curvature in heat-assisted magnetic recording”, IEEE Trans. Magn. 60(5), 3200405, (2024).
[2] S. Greaves, “Three-dimensional magnetic recording”, J. Magn. Magn. Mater. 588, 171343, (2023).
[3] T. Ise, S. J. Greaves and Y. Tanaka, “Controlling information flow in arrays of spin-torque oscillators”, IEEE Trans. Mag. 59(11), 1400405, (2023).
[4] J. Pires, A. Sayyafan, B. Belzer, K. Sivakumar and S. Greaves, “Architecture optimization of a CNN media noise estimator for TDMR”, IEEE Trans. Magn. 60(5), 3000206, (2024).
[5] Y. Tanaka, “Magnetic data storage technology: from perpendicular magnetic recording to the computational storage integration”, Proc. SPIE 12656, Spintronics XVI, 126560K, (2023).

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: Theoretical discovery of the Coulomb drag instability (left) and Zener-Klein tunnel instability (middle) of graphene Dirac plasmons in graphene-channel FETs and their exceptional giant negative conductivity properties (right).

Bottom: Schematic view of a grating-gate terahertz plasmonic detector and 3D rectification effect (left) and scanning-electron-microscope image and measured detector responsivity at 0.8 THz (right).

We are developing novel, integrated electron devices and circuit systems operating in the terahertz (THz) region. First, based on the prior works of an experimental demonstration of room-temperature laser amplification using the graphene Dirac plasmon instability in a graphene transistor, we theoretically discovered new instability mechanism originating from the Coulomb drag effect of the graphene Dirac plasmons and the Zener-Klein tunneling of graphene Dirac fermions, and clarified its superior THz gain bandwidth characteristics (two top-cover featured articles in 2023). Second, regarding InGaAs high-electron-mobility-transistor-based THz plasmonic detectors with original metallic diffraction-grating structures, we demonstrated that the "3D rectification effect", where the diode current nonlinearity associated with the electron tunneling is superimposed onto the plasmonic hydrodynamic nonlinearities, can take place by applying a forward gate bias voltage and succeeded in drastic enhancement of the detector responsivity by one order of magnitude (press released on Nov. 2023).

[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] A. Satou, T. Negoro, K. Narita, T. Hosotani, K. Tamura, C. Tang, T.-T. Lin, P.-E. Retaux, Y. Takida, H. Minamide, T. Suemitsu, and T. Otsuji, "Gate-readout and a 3D rectification effect for giant responsivity enhancement of asymmetric dual-grating-gate plasmonic terahertz detectors," Nanophotonics, vol. 12, iss. 23, pp. 4283-4295, Nov. 2023. DOI: 10.1515/nanoph-2023-0256

[2] V. Ryzhii, C. Tang, T. Otsuji, M. Ryzhii, V. Mitin, and M.S. Shur, "Resonant plasmonic detection of terahertz radiation in field-effect transistors with the graphene channel and the black-AsxP1−x gate layer," Sci. Rep., vol. 13, pp. 9665-1-10, June 2023. DOI: 10.1038/s41598-023-36802-0

[3] V. Ryzhii, C. Tang, T. Otsuji, M. Ryzhii, V. Mitin, and M. S. Shur, "Effect of electron thermal conductivity on resonant plasmonic detection in terahertz hot-electron bolometers based on metal/black-AsP/graphene FETs," Phys. Rev. Appl., vol. 19, pp. 064033-1-10, June 2023. DOI: 10.1103/PhysRevApplied.19.064033

Contact to Professor OTSUJI Taiichi : taiichi.otsuji.e8@tohoku.ac.jp

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, Concurrent Professor
(G. School of Science)

[Research Target and Activities]

Our goal is to develop quantum information devices and systems utilizing quantum interaction between photons and electrons in solids. In 2023, we have achieved (1) development of plasmon-enhanced single photon source coupled to an optical nanofiber, (2) optical trapping and transport of nanoparticles on an optical nanofiber, (3) development of ultra-low-loss, polarization-maintaining photon switch, (4) generation of ultrapure heralded single photons via controlled quasi-phase-matched parametric down-conversion, and (5) evaluation of error-disturbance uncertainty relation using small-scale superconducting quantum computer.

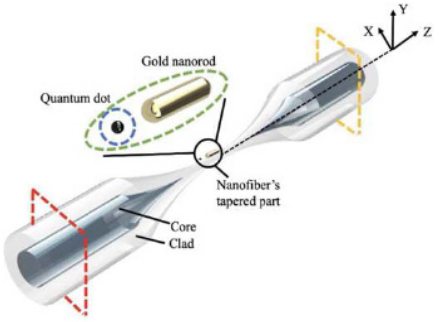


Fig. 1. Plasmon-enhanced single photon source on an optical nanofiber.

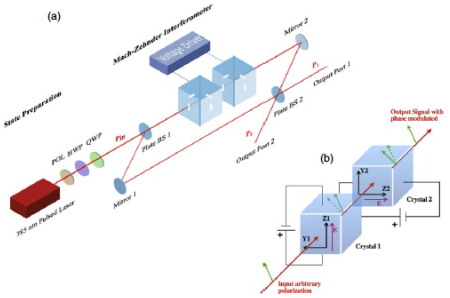


Fig. 2. Ultra-low-loss polarization-maintaining optical switch.

[Staff]

Professor: Keiichi Edamatsu, Dr.
Concurrent Professor : Fumihiro Kaneda, Dr. (Graduate School of Science, Tohoku University)

[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, and an Associate professor in Research Institute of Electric Communication, Tohoku University.

[Papers]

[1] A. Syouji, R. Shimizu, S. Nagano, K. Suizu, and K. Edamatsu, "Short interference fringe and high event rate of two-photon interference using up-converted photon pairs", Jpn. J. Appl. Phys. **62**, 022003/1-4 (2023) doi: 10.35848/1347-4065/acb874
[2] Y. Xuan, R. Sun, S.-Y. Baek. M. Sadgrove, and K. Edamatsu, "Numerical investigation of plasmon-enhanced emission from a nanofiber coupled single photon emitter", Appl. Phys. Exp. **17**, 012003/1-6 (2024) doi: 10.35848/1882-0786/ad1318
[3] P. Wang, S.-Y. Baek, K. Edamatsu, and F. Kaneda, "Low-loss polarization-maintaining optical router for photonic quantum information processing", Jpn. J. Appl. Phys. **63**, 040901/1-5 (2024) doi: 10.35848/1347-4065/ad3533

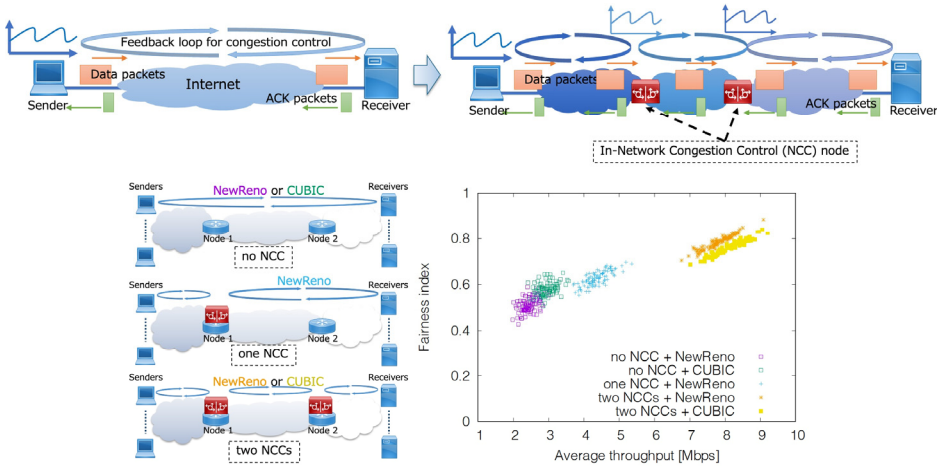
Network Architecture Lab

Information Network Architecture for IoT/AI Societies

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



in-Network Congestion Control

[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] Satoshi Utsumi and Go Hasegawa, "A New Congestion-Based Congestion Control for Low Latency and Low Packet Drop Rate," in Proceedings of IEEE ICUFN 2023, July 2023.
[2] Kodai Tanabe, Go Hasegawa, and Gen Kitagata, "Adaptive compression of operational commands for remote network management over LPWA," in Proceedings of IEEE ITNAC 2023, November-December 2023.
[3] Mitsihiro Watanabe and Go Hasegawa, "In-Network Congestion Control Toward Enhanced Network Resource Utilization," in Proceedings of IEEE ICOIN 2024, January 2024.

Contact to Professor HASEGAWA Go : go.hasegawa.a6@tohoku.ac.jp

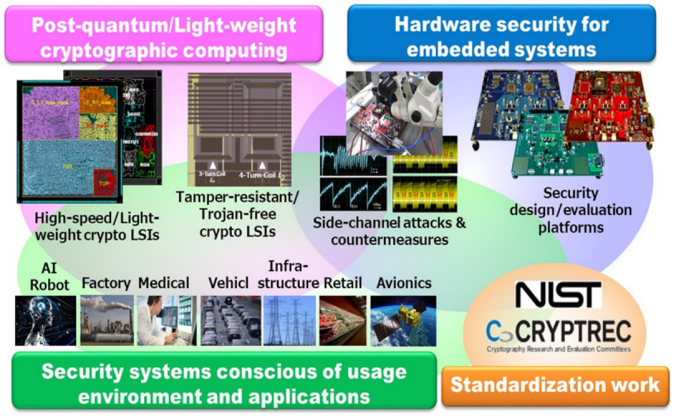
Environmentally Conscious Secure Information System Laboratory

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 efficient implementation attacks on post-quantum cryptography (PQC), including Crystals–Kyber, which is a winner of NIST PQC standardization competition. We validated the attacks experimentally, developed their countermeasure, and confirmed the effectiveness through comprehensive experiments. In addition, we have developed an efficient rekeying scheme, called LR4: Leakage-Resilient Rekeying with Random oracle Repetition, for guaranteeing a long-term security of cryptographic implementation. Furthermore, we have formulated the security and functional require- ments necessary for Cache- Randomization, designed a block cipher with an ultra-low delay specialized for it, called SCARF, and evaluated its hardware performance at the architecture level [3].



[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, the German Innovation Award in 2018, and Docomo Mobile Science Award in 2022.

[Papers]

[1] Rei Ueno, Naofumi Homma, Akiko Inoue, and Kazuhiko Minematsu, “Fallen Sanctuary: A Higher-Order and Leakage-Resilient Rekeying Scheme,” IACR Transactions on Cryptographic Hardware and Embedded Systems, 2024(1), pp. 264-308, 2023.
[2] Yutaro Tanaka, Rei Ueno, Keita Xagawa, Akira Ito, Junko Takahashi, and Naofumi Homma, “Multiple-Valued Plaintext-Checking Side-Channel Attacks on Post-Quantum KEMs,” IACR Transactions on Cryptographic Hardware and Embedded Systems, 2023(3), pp.473–503, 2023.
[3] Federico Canale, Tim Güneysu, Gregor Leander, Jan Philipp Thoma, Yosuke Todo, and Rei Ueno, “SCARF---A Low-Latency Block Cipher for Secure Cache-Randomization,” USENIX Security Synposium '23, pp.1937–1954, Anaheim, CA, USA, August 2023.

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) Real-world computing, (5) Nano-Bio Hybrid Molecular Devices, (6) Interactive Content, (7) Soft Computing Integrated System.

The goals and achievements in the fiscal year 2023 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 developed a high-frequency magnetic field measurement system using a pulsed laser and magnetic garnet. Applied to commercial analog high-frequency circuits (frequency synthesizers), it detected the strongest leakage magnetic field near the center of an IC chip, which was previously undetectable. This system can measure magnetic fields in various electronic circuits. We also devised a new method for fabricating magnetic garnet materials, enhancing high-frequency measurements and creating magneto-optical devices. By using a laser to locally heat and crystallize the magnetic garnet, we produced magneto-optical materials on semiconductor and optical circuit substrates. These advancements improve system performance and enable new device development.

(2) Advanced Acoustic Information Systems

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

(Achievements) We have focused on how people organize auditory objects from simultaneously presented auditory information. In 2023, we investigated the effect of various acoustic features on organizing auditory objects, such as frequency, sound pressure level, and spatial information. We also investigated the replicability of the proportion of people with aphantasia, a condition wherein individuals have a reduced or absent construction of voluntary visual imagery, using both criteria in the same population of participants. 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 sound space recording method using distributed spherical microphone arrays.

(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 2023, our major achievements were the followings. 1) We revealed that there is visual attention to focus on the location of hand movement goal that is independent of top-down attention. Since our experiments showed that the two types of attention have different spatial tunings, they are likely to have different roles in visual processing. 2) We investigated inter-individual estimation of attentional levels during learning using facial expressions. Although a machine leranig (ML) method predicts attention level from facial expressions, prediction accuracy is extremely low for individuals whose data are not used in learning phase of the ML method.

(4) 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 2023 are summarized as follows: (1) We have observed and modeled adaptive locomotion of tubificine worm blobs in a confined environment, (2) we have proposed a control scheme that allows a quadruped robot to realize flexible turning gait according to the center of mass position, (3) we have designed a quadruped robot that has flexible body based on anatomical findings.

(5) 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) The main achievements in 2023 are as follows: (1) We developed an automated analysis system to classify channel currents, which are time-series data showing the function of ion channel proteins, into two levels corresponding to the open/closed state of the channel. (2) Using microfluidic devices, we have realized an artificial neuronal circuit called a modular structure and evaluated the effects of inflammatory cytokines on the spontaneous activity patterns of neuronal circuits. (3) Using electrochemiluminescence imaging, we constructed a measurement system that can monitor respiratory activity and metabolic changes of spheroids, which are expected to be utilized in the fields of regenerative medicine and drug discovery.

(6) Interactive Content Design

(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 exploring visual-auditory redirected walking using auditory cues in reality, door-opening redirection with dynamic haptics in room-scale VR, real-time reconstruction of fluid flow under unknown disturbance, and surroundings-aware remote drone piloting using an augmented third-person perspective.

(7) Soft Computing Integrated System

(Aims) 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.

(Achievements) In this year, we proposed a neuron model introducing predictive dynamics and applied it to reservoir neural networks, and found that it improves time-series prediction performance and that the exponential decay property of memory capacity with respect to time delay contributes to the performance improvement. In addition, to implement the spatiotemporal contextual learning and memory network (STCLMN) model as an event-driven spiking neural network learning integrated circuit system, we described it as continuous-value and -time differential/difference equations giving eSTCLMN model. Furthermore, we demonstrated feasibility of the eSTCLMN model with a prototype circuit.

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.

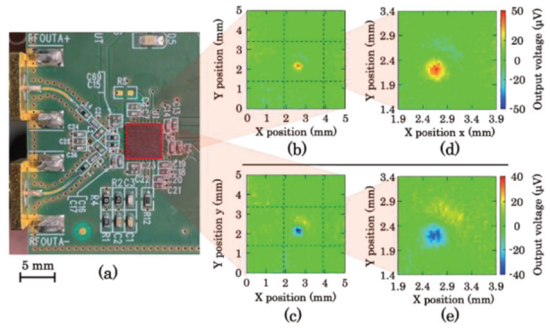


Fig. 1. Measurement of the leakage magnetic field distribution generated by a commercial analog high-frequency circuit. This method revealed a significant leakage magnetic field in the central part of the chip.

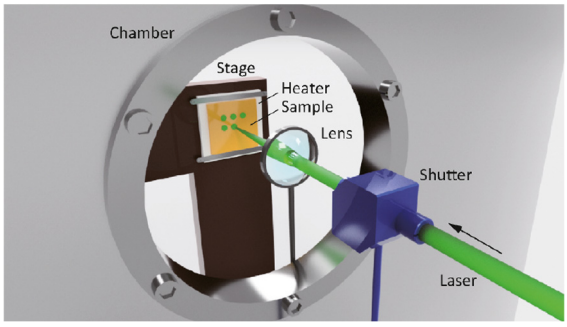


Fig. 2. Magneto-optical materials used in magnetic sensors and optical communications were fabricated using localized laser heating. This enabled the integration of magneto-optical materials with semiconductor circuits and optical circuits.

[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, Kazushi Ishiyama, Toshiaki Watanabe, Pang Boey Lim, Mitsuteru Inoue, Caroline A. Ross, and Taichi Goto, "Growth of magnetooptical cerium-substituted yttrium iron garnet on yttrium aluminum garnet using ion beam sputtering," Applied Physics Letters, Vol. 123, p. 112404, 2023.
[2] Hibiki Miyashita, Yuki Yoshihara, Kanta Mori, Takumi Koguchi, Pang Boey Lim, Mitsuteru Inoue, Kazushi Ishiyama, and Taichi Goto, "Vacuum laser annealing of magnetooptical cerium-substituted yttrium iron garnet films," Optical Materials, Vol. 146, p. 114530, 2023.
[3] Kanta Mori, Takumi Koguchi, Toshiaki Watanabe, Yuki Yoshihara, Hibiki Miyashita, Dirk Grundler, Mitsuteru Inoue, Kazushi Ishiyama, and Taichi Goto, "Orientation-dependent two-dimensional magnonic crystal modes in an ultralow-damping ferrimagnetic waveguide containing repositioned hexagonal lattices of Cu disks," Physical Review Applied, Vol. 21, p. 014061, 2024.

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.

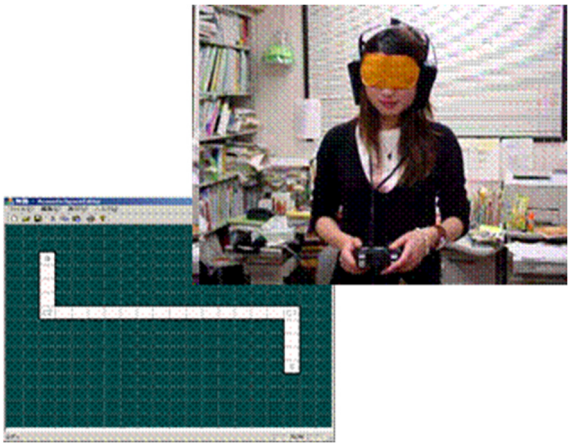


Fig. 1 Application for the training of spatial cognition using a high-definition virtual auditory display

In FY2023, we focused on the mechanism of auditory scene analysis. The auditory scene analysis is a well-known streaming phenomenon which is observed when listeners group several sounds into "auditory objects" in complex auditory scenes. This year, we investigated the tolerance thresholds for the angular disparity at which the sound sources would segregate rather than group together into single auditory objects. The results revealed that listeners tend to perceive the presented sequences as a single stream when the angular disparity was small; however, these tolerance thresholds depended on the spatial region within which the sequences were presented [1]. These results were consistent with the minimum audible angle on the horizontal plane.

[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. Sakamoto and M. Tamakawa, “The effect of angular disparity between sound source sequences on the perceptual organization of auditory objects,” Proc. 185th Meeting of the Acoustical Society of America (Acoustics 2023), 3pPPa10 (2023).

[2] J. Takahashi, G. Saito, K. Omura, D. Yasunaga, S. Sugimura, S. Sakamoto, T. Horikawa, and J. Gyoba, “Diversity of aphantasia revealed by multiple assessments of visual imagery, multisensory imagery, and cognitive style,” Frontiers in Psychology, 14, 1174873 (2023).

[3] S. Sakamoto and K. Katada, “Sound field recording using distributed spherical microphone arrays based on a virtual spherical model (invited lecture),” Proc. INTERNOISE2023, 1-5-17, (6-page manuscript) (2023).

Contact to Professor SAKAMOTO Syuichi : shuichi.sakamoto.d5@tohoku.ac.jp

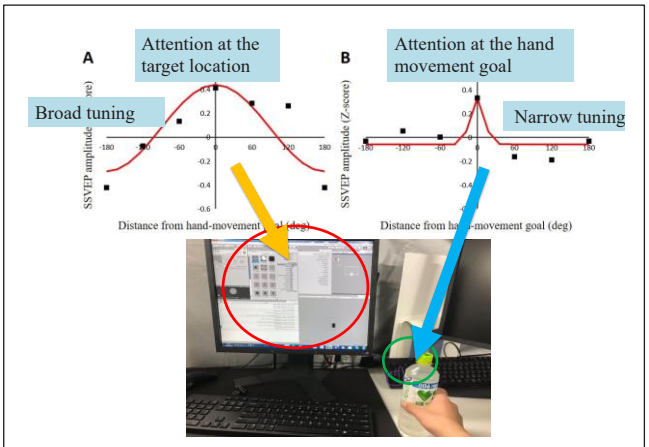
Visual Cognition and Systems Laboratory

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 visual attention at around the location of hand movement goal. Separate estimations of attention modulation for the location and the focus of the top-down attention revealed that there is a process to orient attention to the hand movement goal, which is different from the top-down attention. Since the attention to hand movement goal is effective within a smaller area than the top-down attention, the two attention processes have likely different functions. 2) To investigate how actions lead to intention expression and understanding and how the cultures influence this capacity is clarified, we approached these endeavors by recruiting professional performers to our lab. Their movements, recorded by a motion capture system (Vicon), were converted to dynamic point-light animations. An additional naïve observers viewed these animations and reported the perceived impression in an online experiment platform. We discovered that (1) naïve participants could judge the emotion from the movements well above chance, (2) Japanese participants are superior to detect negative expressions than the non-Japanese participants, and (3) observers have near-perfect performance to judge friendliness over hostility. We plan to investigate same-race advantage and cultural effects from this paradigm, and will continue to delineate the mechanisms in the future.



The attention to a hand movement goal is narrowly tuned while top-dow attention typically spreads broadly around the attention focus.

[Staff]

Professor : Satoshi Shioiri, Ph.D.

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

[Profile]

Satoshi SHIOIRI: Professor Shioiri graduated Tokyo Institute of Technology and received Dr. Eng in 1986. Then, he was a postdoctoral researcher at University of Montreal until 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] Wei Wu, Zhan Li, Takumi Miura, Yasuhiro Hatori, Chia-huei Tseng, Ichiro Kuriki, Yoshiyuki Sato, Satoshi Shioiri; Different Mechanisms for Visual Attention at the Hand-movement Goal and Endogenous Visual Attention. *J Cogn Neurosci* 2023; 35 (8): 1246–1261

[2] Spillmann, L., Hsu, L.C., Wang, W. Chen, C.C., Yeh, C.I., Tseng, C.H.. Gestalt neurons and emergent properties in visual perception: a novel concept for the transformation from local to global processing. *Journal of Vision, 23(12):8, 1-5*. (2023)

[3] Fujiwara, K., Cheng, M., Tseng, C.H., Kitamura, Y. Reading emotions from bodily movements: The development of the Motion Unit AI. *Journal of Information Processing*. (2023)

Real-world Computing

Toward Understanding Design Principle for Life-like Resilient Systems

Real-world Computing, Akio Ishiguro, Professor
Real-world Mathematical Modeling, Takeshi Kano, Associate 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 locomotion of tubificine worm blobs in a confined environment

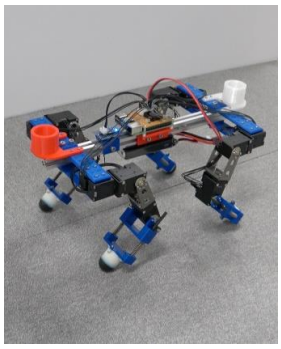


Fig.2: Quadruped robot that realizes a turning gait according to the center of mass position

[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] Mikami T, Wakita D, Kobayashi R, Ishiguro A, Kano T (2023) Elongating, entwining, and dragging: mechanism for adaptive locomotion of tubificine worm blobs in a confined environment. Front. neurorobot, 17:1207374.
[2] Amaike, H., Fukuhara, A., Kano, T., & Ishiguro, A. (2023). Decentralized Control Mechanism Underlying Morphology-Dependent Quadruped Turning. Journal of Robotics and Mechatronics, 35(5), 1290-1299. https://doi.org/10.20965/jrm.2023.p1290

Nano-Bio Hybrid Molecular Devices

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

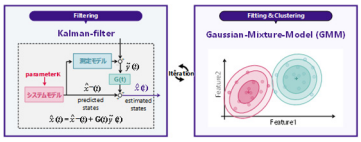
Nano-Bio Hybrid Molecular Devices: Ayumi Hirano-Iwata, Professor

[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. Adaptive automatic analysis system for picoampere currents

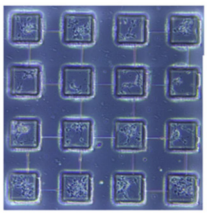
We developed an automated analysis system to classify the current values at each time point into two levels corresponding to the open and closed states of the channel. This system showed a higher accuracy rate than the conventional 50% threshold for about 80% of the pseudo-channel current data sets. The analysis program and the pseudo-channel current data set are available on the research data repository Zenodo.



Adaptive automatic analysis system for channel currents

2. Biomedical application of artificial neuronal networks

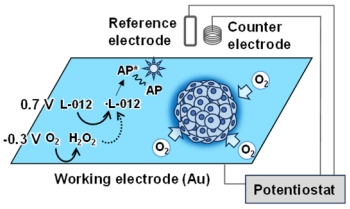
By patterning neurons using microfluidic devices, we realized artificial neuronal networks that mimic the modular organization found in the nervous system. We investigated the effect of IL-6 on the spontaneous activity patterns of the neuronal networks and found that exposure to IL-6 increased the synchrony of neuronal activity, and that this effect was more pronounced in networks with high modularity.



Neuronal circuits formed in a microfluidic device

3. Evaluation of spheroid activity using electrochemiluminescence imaging

Spheroids, produced by self-assembly of cells in a 3D culture environment, are promising *in vitro* models for regenerative medicine and drug discovery. We evaluated the metabolic activity of spheroids using electrochemiluminescence imaging. We reported the effective use of this system to evaluate drug efficacy by measuring changes in the respiratory rate of breast cancer cell spheroids. We also succeeded in monitoring the changes in the metabolic activity associated with osteogenesis induction of mesenchymal stem cell spheroids.



Electrochemiluminescence imaging of a cellular spheroid

[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 American Chemical Society. The Japan Society of Applied Physics, The Japan Society of Vacuum and Surface Science.

[Papers]

[1] M. Sato, M. Hariyama, M. Komiya, K. Suzuki, Y. Tozawa, H. Yamamoto, A. Hirano-Iwata, "Model-free idealization: Adaptive integrated approach for idealization of ion channel currents", *Biophys. J*, **122**, 3959-3975 (2023).

[2] M. Sakaibara, H. Yamamoto, H. Murota, N. Monma, S. Sato, A. Hirano-Iwata, "Enhanced responses to inflammatory cytokine interleukin-6 in micropatterned networks of cultured cortical neurons", *Biochem. Biophys. Res. Commun.*, **695**, 149379 (2024).

[3] K. Hiramoto, K. Komatsu, R. Shikuwa, A. Konno, Y. Sato, A. Hirano-Iwata, K. Ino, H. Shiku, "Evaluation of respiratory and secretory activities of multicellular spheroids via electrochemiluminescence imaging", *Electrochimica Acta*, **458**, 142507 (2023).

Contact to Professor HIRANO Ayumi : ayumi.hirano.a5@tohoku.ac.jp

Interactive Content

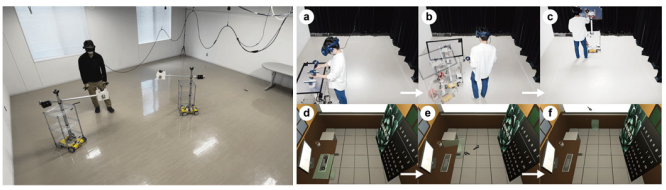
Technologies for Interactive Content

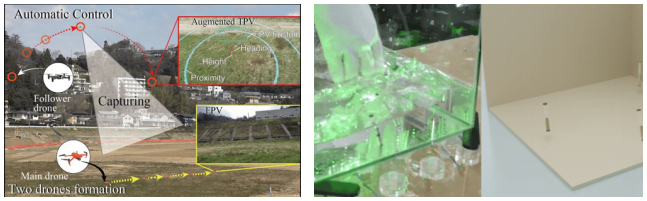
Interactive Content Design **Yoshifumi KITAMURA, Professor**
Human-Content Interaction **Kazuki TAKASHIMA, Associate Professor**

[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 visuo-haptic door-opening redirection system in room-scale VR, a robotic touch surface for supporting mid-air interaction in VR, a real-time reconstruction technique of fluid flow under unknown disturbance, and a drone-piloting user interface using an augmented third-person perspective.





[Staff]

Professor: Yoshifumi Kitamura, Dr.
Associate Professor: Kazuki Takashima, Dr.
Assistant Professor: Kazuyuki Fujita, Dr.
Assistant Professor: Kaori Ikematsu, 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] Yukai Hoshikawa, Kazuyuki Fujita, Kazuki Takashima, Morten Fjeld, Yoshifumi Kitamura, RedirectedDoors+: Door-Opening Redirection with Dynamic Haptics in Room-Scale VR, IEEE Transactions on Visualization and Computer Graphics, Vol. 30, Issue: 5, pp. 2276-2286, Mar. 2024.
[2] Kinfung Chu, Jiawei Huang, Hidemasa Takana, Yoshifumi Kitamura, Real-Time Reconstruction of Fluid Flow under Unknown Disturbance. ACM Trans. Graph. Vol. 43, Issue: 1, Article 4, 14 pages, Oct. 2023.
[3] Maakito Inoue, Kazuki Takashima, Kazuyuki Fujita, Yoshifumi 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 (CHI '23), Article No. 31, pp. 1-19, May. 2023.

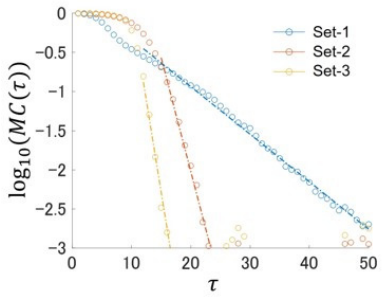
Soft Computing Integrated System

Brainmorphic Computing Hardware System

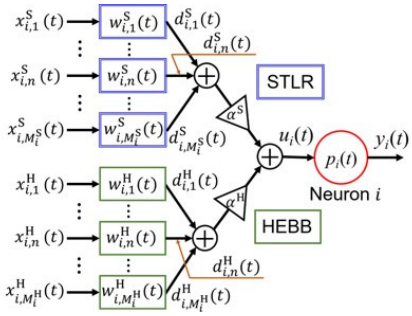
Soft Computing Integrated System **Yoshihiko Horio, Professor**

[Research Target and Activities]

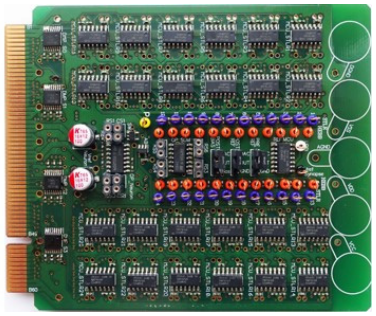
We are working on a "brainmorphic" computing hardware (BMCHW) system, and developing integrated circuit and device technologies suitable for BMCHW. During the FIY 2023; 1) We proposed a prospective neuron model with self-feedbacks of its internal state and output. We then applied the proposed model to the reservoir neurons or output neurons in a reservoir neural network. Through simulations, we showed the effectiveness of the prospective neurons. 2) We proposed an extended spatiotemporal contextual learning and memory network (eSTCLMN) model for an event-driven spiking neural network hardware. We also proposed a Hamming distance histogram and a multi-stage 2D map technique for evaluation of learning performance of the eSTCLMN model. We built a prototype circuit for eSTCLMN using discrete circuit elements.



Memory capacity characteristics of the proposed prospective reservoir.



Neuron in the eSTCLMN model.



Prototype of the eSTCLMN.

[Staff]

Professor : Yoshihiko Horio, Ph.D.
Specially Appointed Assistant Professor : Takemori Orima, Dr.
Technical Assistants : Mariko Takahashi and Chikako Hibino

[Profile]

Yoshihiko Horio received the Ph.D. degree from Keio University in 1987. He is currently a Professor with the Research Institute of Electrical Communication, Tohoku University. From 1987 to 2016, he was with Department of Electronic Engineering, Tokyo Denki University being a Professor from 2000. From 1992 to 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 and brain-inspired VLSI systems. Dr. Horio is a Fellow of the IEICE and Emeritus Professor of Tokyo Denki University.

[Papers]

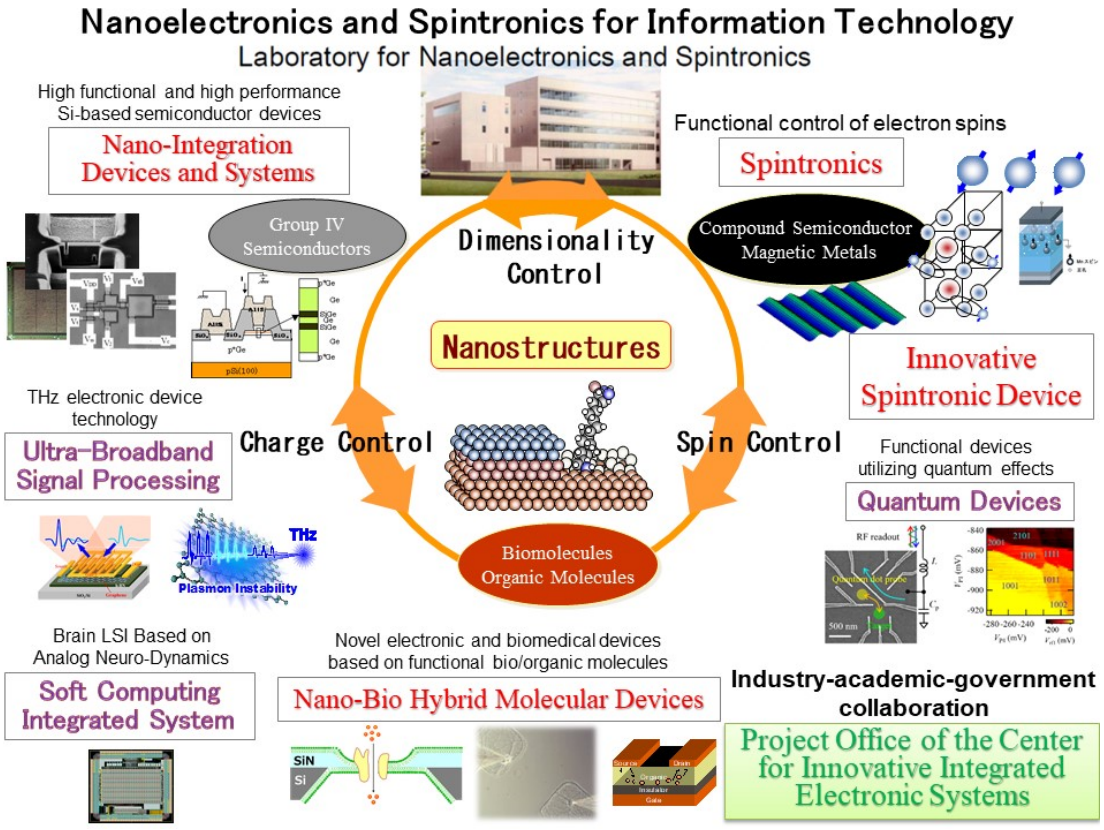
[1] T. Orima, T. Tsuji, and Y. Horio, "An extended spatiotemporal contextual learning and memory network model for hardware implementation," Procedia Computer Science, vol. 222, pp. 478-487, 2023. DOI: 10.1016/j.procs.2023.08.186
[2] Go Ishii, Yoshihiko Horio, and Takemori Orima, "Effect of memory capacity characteristics on time-series prediction in reservoir neural network consisting of neurons with local temporal history," in Proc. KJCCS, BP-6, 2024. (Best Student Paper Award).
[3] T. Tsuji, T. Orima, and Y. Horio, "Detailed evaluation of spatiotemporal learning rule based on Hamming distances among output vectors," in Proc. NOLTA, pp. 415-418, 2023.

Contact to Professor HORIO Yoshihiko : yoshihiko.horio.a3@tohoku.ac.jp

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 Systems, 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 2023 are shown below.

Nano Integration

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

(1) A reservoir computing system has been configured using a spiking neural network LSI that reproduces various neural pulses and operates at extremely low power. Electrical measurements confirmed that the system could correctly classify data such as voice and handwritten text at low power.

(2) To develop Esaki diode, heavily P-doped Si film deposition with a carrier concentration of $2x10^{20}$ cm^{-3} was realized by using ECR plasma CVD. Moreover, we developed a pn junction diode fabrication process using wet etching of the P-doped Si, and confirmed good rectifying characteristics.

(3) We showed that micropatterned neuronal networks can be integrated in the reservoir computing paradigm to study the computational advantages of non-random network organizations.

● Soft Computing Integrated System (Y. Horio)

We are working on a brain-inspired brainmorphic computing hardware system using an analog VLSI as a core component. Results of this year are summarized as follows:

(1) We proposed a neuron model that introduces predictive dynamics in the neuron itself, and investigated the use of this model as (A) a reservoir layer neuron and (B) an output layer neuron in a reservoir neural network, respectively. In (A), we derived a sufficient condition for the echo-state property enabling the design of the network. Furthermore, we showed that predictive dynamics improves the closed-loop prediction performance of time-series, which is attributed to the exponential decay property of the memory capacity. On the other hand, in (B), simulation experiments revealed that the one-step prediction performance of chaotic time series is improved.

(2) To implement the spatiotemporal contextual learning and memory network model as an event-driven spiking neural network learning circuit system, we described it as continuous-value and -time differential/difference equations. In addition, a prototype of a mixed analog/digital circuit was implemented using off-the-shelf components to confirm the feasibility of the proposed circuit. Because it is difficult to evaluate the learning performance by extracting each synaptic weight value in integrated circuits, we proposed the Hamming distance histogram and its hierarchical 2-D map method to evaluate the learning performance from the observable network outputs.

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) elucidating magnetic order in nanoscale gyroid network using micromagnetic simulation, (2) finding fundamental difference in the response of magnetic octupole to the spin-orbit torque from that of magnetic dipole, (3) establishing a method to prepare directed self-assembly of diamond network in triblock terpolymer films, (4) demonstrating the feed-forward stochastic neural network using fast fluctuating stochastic magnetic tunnel junction, (5) identifying the limitation of packing density of ultra-small magnetic tunnel junction for high-density STT-MRAM, (6) summarizing the tips to develop ultrasmall magnetic tunnel junction for retention-critical and speed-critical applications, (7) demonstrating heterogeneous probabilistic computer consisting of a deterministic CMOS circuit and stochastic magnetic tunnel junctions.

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

The goal of our research is to explore the terahertz frequency range by creating novel integrated electron devices and circuit systems. III-V- and graphene-based active plasmonic heterostructures for creating new types of terahertz lasers and ultrafast transistors are major concerns. 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 2023 FY.

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

We have developed a new principle current-injection terahertz laser transistor based on the properties of Dirac plasmon, a quantum charge oscillation in graphene in which electrons and holes behave as relativistic Dirac particles, and have successfully demonstrated a terahertz laser transistor with a maximum gain of 9% derived from plasmon instability under room temperature using a prototype device with a unique asymmetric double-diffraction grating gate structure. In this year, we theoretically discovered new instability mechanisms originating from the Coulomb drag effect of the Dirac plasmons and the Zener-Klein tunneling effect of Dirac fermions, and clarified its superior terahertz gain bandwidth characteristics. (3 international peer-reviewed papers; 10 invited talks at international conferences).

2. Development of plasmonic terahertz detectors

For future ultrahigh-speed wireless communications, we have developed plasmonic terahertz detectors with original metallic diffraction-grating structures, which utilize hydrodynamic nonlinearities of two-dimensional plasmons in the channels of InGaAs high-electron-mobility transistors (InGaAs-HEMTs). This fiscal year, we demonstrated that the "3D rectification effect", where the diode current nonlinearity associated with the electron tunneling is superimposed onto the plasmonic hydrodynamic nonlinearities, can take place by applying a positive gate bias voltage in the gate-readout configuration of the output signal and succeeded in drastic enhancement of the detector responsivity by one order of magnitude (Press-released on November 2023).

● **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 2023 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-speed electronics and developed techniques for new materials.

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

(3) We studied semiconductor quantum bits for future quantum information processing. We worked on quantum bit operations and readouts, and developed techniques for scaling up the systems and creating 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 developed an automated analysis system to classify the current values at each time point into two levels corresponding to the open and closed states of the channel. This system showed a higher accuracy rate than the conventional 50% threshold for about 80% of the pseudo-channel current data sets. The analysis program and the pseudo-channel current data set are available on the research data repository Zenodo.

(2) By patterning neurons using microfluidic devices, we realized artificial neuronal networks that mimic the modular organization found in the nervous system. We investigated the effect of IL-6 on the spontaneous activity patterns of the neuronal networks and found that exposure to IL-6 increased the synchrony of neuronal activity, and that this effect was more pronounced in networks with high modularity.

(3) Spheroids, produced by self-assembly of cells in a 3D culture environment, are promising *in vitro* models for regenerative medicine and drug discovery. We evaluated the metabolic activity of spheroids using electrochemiluminescence imaging. We reported the effective use of this system to evaluate drug efficacy by measuring changes in the respiratory rate of breast cancer cell spheroids. We also succeeded in monitoring the changes in the metabolic activity associated with osteogenesis induction of mesenchymal stem cell spheroids.

Research Targets and Activities of Laboratory for Brainware Systems

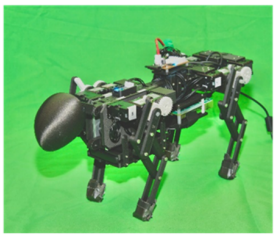
The Laboratory for Brainware Systems of the Research Institute of Electrical Communication was established in 2004 and renewed in 2014. Its purpose is to contribute to the research and development of advanced information science and technology for Brainware systems which realize a seamless fusion of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

Seamless Fusion of Real World and Multi-Modal Computing

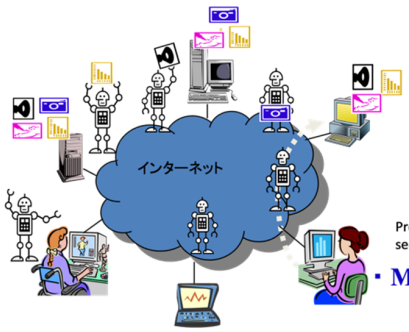


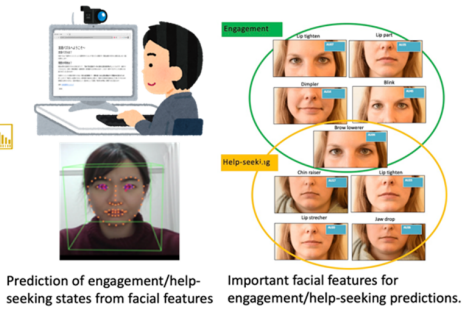
・**Real-World Dynamical Intelligence**

(Real-World Computing)

・**Brain-Like Computing**

(Brain Architecture)





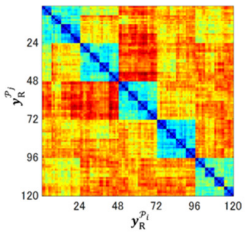
Prediction of engagement/help-seeking states from facial features

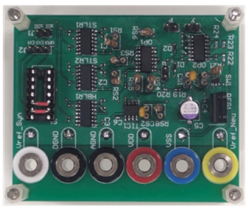
Important facial features for engagement/help-seeking predictions.

・**Mental state prediction from facial feature**

(Recognition and Learning Systems)

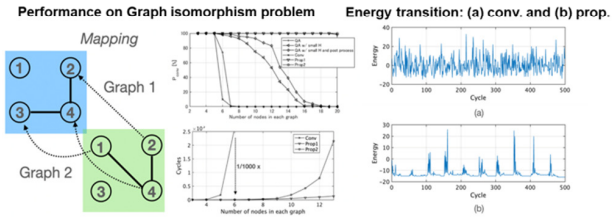
Hardware Environment with Massively Parallel Brain LSI





・**Analysis and Implementation of Spatiotemporal NNs**

(Soft Computing Integrated System)



・**Fast Solving Larger Combinatorial Opt. Problem**

(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 2023 are an important step towards the goal as:

--Real-World Computing Section has proposed a swarm model of tubificine worm blobs locomotion in a confined environment.
https://www.frontiersin.org/articles/10.3389/frobt.2022.992716/full

--New Paradigm VLSI System Section has successfully solved large-scale combinatorial optimization problems with more than 1,000 nodes by utilizing stochastic computing.
https://doi.org/10.1109/TNNLS.2022.3159713

--Cross-cultural comparison of lexical partitioning of color space
https://scholar.google.co.jp/citations?view_op=view_citation&hl=ja&user=I9qDcUsAAAAJ&sortby=pubdate&citation_for_view=I9qDcUsAAAAJ:cRMvf6lLvU8C
https://dl.acm.org/doi/abs/10.1145/3573051.3596182

--Soft Computing Integrated System Section succeeded in describing the hippocampal spatiotemporal contextual learning and memory model by differential/difference equations.
https://doi.org/10.1016/j.procs.2023.08.186

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 Human Information Systems 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 published a review paper about the cross-cultural comparison of lexical partitioning of color space. Comparisons of the color naming results in the identical experimental setup among English speakers, Japanese speakers and Taiwnese Chinese speakers showed that the three languages shear similar color categories which uniquely corresponde to color terms. This indicates that it is not difficult to communicate about colors using languages with language translation. On the other hand, however, there are also differences among these languages, such as Mizu-iro (water color) in Japanese appears to be unique. There is a piece of evidence for influence of cultures on color categories.

Seconds, we investigated the mechanism of auditory scene analysis. In the experiment, the tolerance thresholds for the angular disparity at which the sound sources would segregate rather than group together into single auditory objects were measured. The results revealed that listeners tend to perceive the presented sound sequences as a single stream when the angular disparity between the sounds was small. Moreover, observed tolerance thresholds became large when the sound sequences were presented from the side, in comparison to the situation when the sequences were presented from in front of the listeners. These results were consistent with the minimum audible angle on the horizontal plane.

[Staff]

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

[Papers]

[1] S Shioiri, R. Tokunaga, I. Kuriki, *Volume 1 Cross-Linguistic Studies*, edited by Masatoshi Koizumi, Berlin, Boston: De Gruyter Mouton, 2023, pp. 41-62.

[2] Kato, H., Takahashi, K., Hatori, Y., Sato, Y., Shioiri, S. (2023). Prediction of Engagement from Facial Expressions: Effect of Dynamic Factors. In: Kondo, K., Horng, MF., Pan, JS., Hu, P. (eds) Advances in Intelligent Information Hiding and Multimedia Signal Processing. IIHMSP 2022. Smart Innovation, Systems and Technologies, vol 339. Springer, Singapore.

[3] S. Sakamoto, M. Tamakawa, "The effect of angular disparity between sound source sequences on the perceptual organization of auditory objects," *Proc. 185th Meeting of the Acoustical Society of America (Acoustics 2023)*, 3pPPa10 (2023).

[4] J. Takahashi, G. Saito, K. Omura, D. Yasunaga, S. Sugimura, S. Sakamoto, T. Horikawa, J. Gyoba, "Diversity of aphantasia revealed by multiple assessments of visual imagery, multisensory imagery, and cognitive style," *Frontiers in Psychology*, 14, 1174873 (2023).

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. The center consists of three devisions, "Industry-Academia-Government-Collaboration Research and Development Division", "Interdisciplinary Collaboration Research Division", and "Exploratory Research Division".

[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
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

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

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

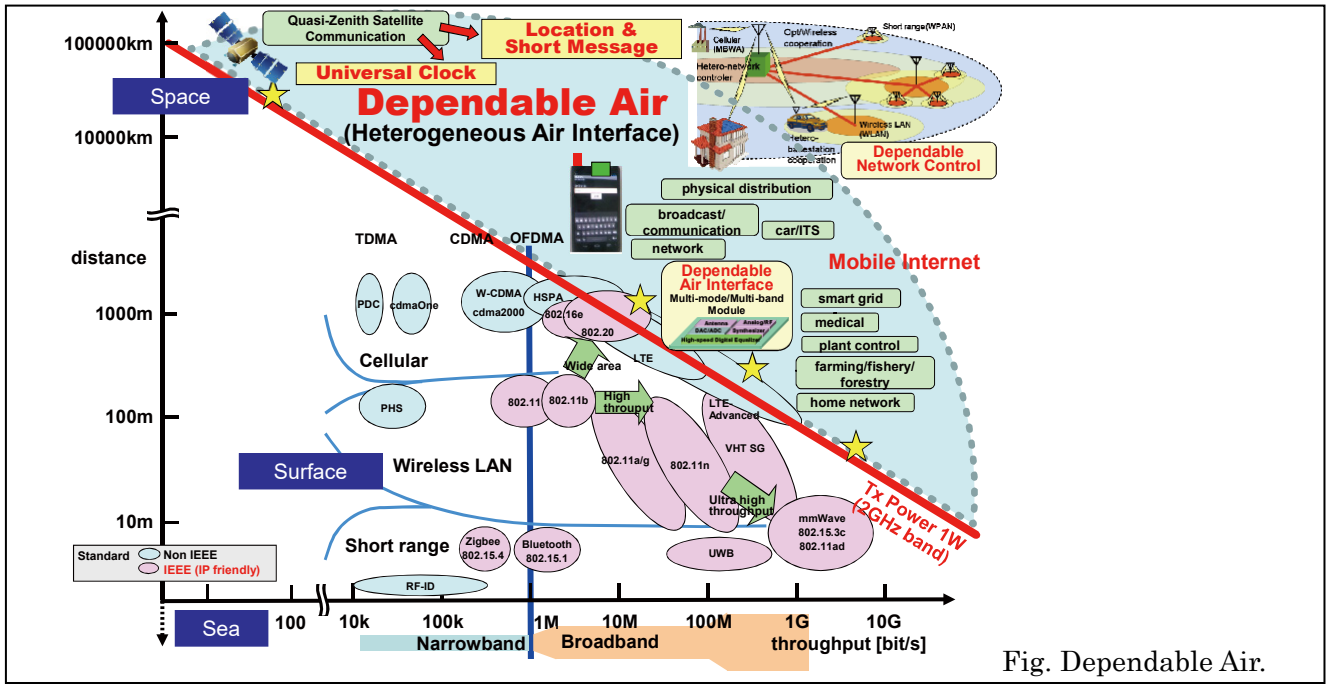


Fig. Dependable Air.

[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 support of MIC. The group also launch a new R&D project relating to millimeter-wave NTN B5G LEO constellation satellite communication systems and on-board DBF antenna/devices under the support of NICT.

[Staff]

Professor: Noriharu Suematsu, Ph.D
Specially Appointed Professor: Takashi Shiba, Ph.D
Specially Appointed Professor: Satoshi Tsukamoto, Ph.D
Researcher: Tamotsu Nishino, Ph.D

[Papers]

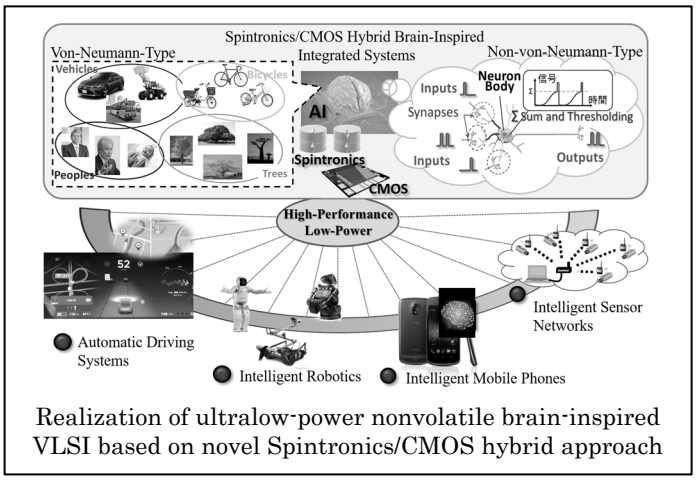
[1] T. Shiba, T. Furuichi, N. Suematsu, "Measurement of Power Delay Profile for Local 5G System," URSI GASS 2023, Sapporo, Japan, 19-16 August 2023.
[2] T. Shiba, T. Furuichi, N. Suematsu, "Power Delay Profile Measurement Applied MUSIC for Local 5G System," 2023 6th World Symposium on Communication Engineering (WSCE), pp. 49-55, September 2023.
[3] N. Suematsu, "Q/V-band direct digital RF transceiver design for LEO constellation on-board DBF antenna," 2023 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), 2023.
[4] J. Zhang, K. Furuuchi, N. Suematsu, "20GHz-Band Low Backlobe Vivaldi Endfire Antenna Array for Digital Beamforming Transmitter Antenna Module," 2023 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), pp. 41-43, 2023.

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]



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 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. In FY2023, we are exploring ways to reduce device power consumption by combining the error tolerance characteristics of neural networks with the switching characteristics of nonvolatile devices. Theoretically, we clarify the relationship between the error tolerance of DNNs and the switching current of nonvolatile devices, and experimentally, we demonstrate a method to reduce power consumption by introducing random errors into low 8-bit DNN parameters without compromising the accuracy of the DNN. Experimental results show that inverting 20% random binary reduces power by 5.63% and inverting 100% binary saves 34.84% energy. Furthermore, incorporating the error maps of six practical STT-MRAM chips with a maximum error rate of 0.00868 into the low 8-bit parameters of the DNN does not affect its accuracy under switching currents corresponding to 100% switching probability (maximum loss is 0.00067). The MobileNet average Top 1 and Top 5 accuracy losses are 0.000355, 0.00079, 0.000670, and 0.000310, respectively, which have only a marginal impact on its industrial application.

The ECC project also proposed a new error correcting code module for future object recognition systems that use STT-MRAM as weight data storage, which guarantees data integrity while achieving high throughput and small area. The proposed ECC module employs pipelined highly parallel BCH modules to address the high throughput requirements of STT-MRAM. To optimize the small area requirements, a 64-parallel linear LFSR for encoders and a parallel factor-reduced decoder are proposed. The code length and correction capability of the BCH code are optimized for high efficiency in terms of memory redundancy and computational complexity. The correction performance of the proposed ECC module is verified on a working STT-MRAM chip and the implementation results show that it achieves a small area of 18.27K μm^2 with 64-bit high throughput

and 5.76 ns read delay. Experimental results show that a bit error rate of less than 2×10^{-3} for STT-MRAM does not affect the recognition accuracy of neural networks. These research results indicate that the ECC module is suitable for most manufactured STT-MRAM chips and can be integrated into object recognition 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. He also received IEEE ISMVL Best Paper Award in 1986 and1988, respectively, Niwa Memorial Award in 1988, Sakai Memorial Award in 2000, LSI Design of the Year Referee's Special Award in 2002, ASP-DAC 2007 Special Feature Award in 2007, JJAP Paper Award in 2009, IEICE Excellent Paper Award in 2010, Ichimura Academic Contribution Award in 2010, IEEE ISVLSI 2010 Best Paper Award in 2010, SSDM Paper Award in 2012, IEEE ASYNC 2014 Best Paper Finalist in 2014, FY2015 Commendation for Science and Technology by the MEXT (research division) in 2015. He is a Senior Member of IEEE.

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] Y. Saito, S. Ikeda, N. Tezuka, H. Inoue, and T. Endoh, “Field-free spin-orbit torque switching and large damping-like spin-orbit torque efficiency in synthetic antiferromagnetic systems using interfacial Dzyaloshinskii-Moriya interaction,” Physical Review B, vol.108, pp.024419, 2023.

[2] Y. Saito, S. Ikeda, H. Inoue, and T. Endoh, “Charge-to-Spin Conversion Efficiency in Synthetic Antiferromagnetic System Using Pt–Cu/Ir/Pt–Cu Spacer Layers,” IEEE Transactions on Magnetics, vol.59, pp.1300405, 2023.

[3] T. Li, Y. Ma, K. Yoshikawa, and T. Endoh, “Neuromorphic processor-oriented hybrid Q-format multiplication with adaptive quantization for tiny YOLO3,” Neural Computing and Applications, vol. 35, issue 15, pp.11013-11041, Feb. 2023. DOI： 10.1007/s00521-023-08280-y.

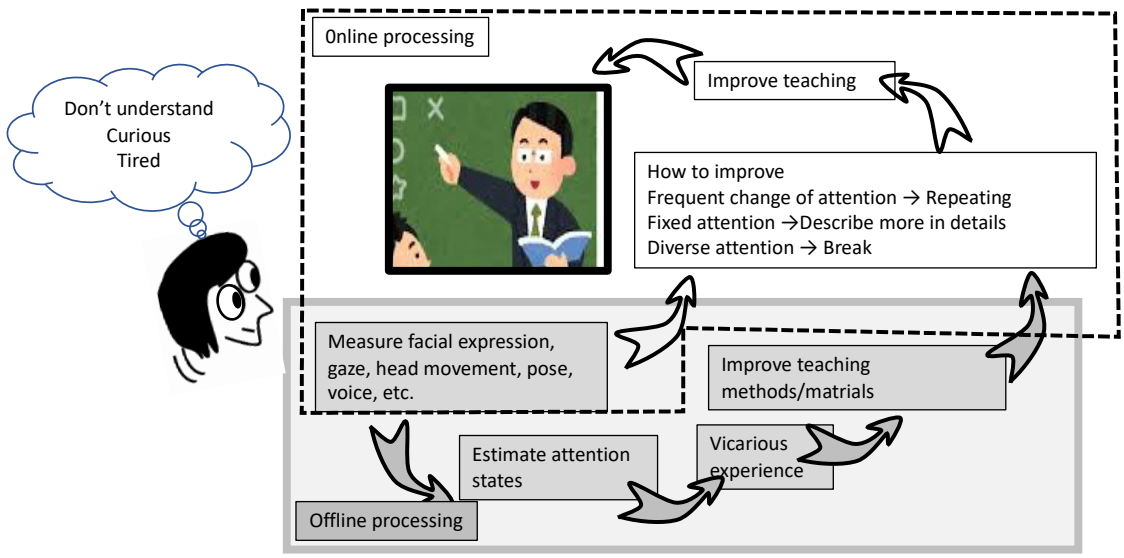
[4] T. Li, Y. Ma, K. Yoshikawa, T. Endoh, “Hybrid signed convolution module with unsigned divide-and-conquer multi- plier for energy-efficient STT-MRAM-based AI accelerator,” IEEE Transactions on Very Large Scale Integration (VLSI) Systems, vol.31, pp.1078-1082, Feb. 2023.

[5] T. Li, L. Zhang, Y. Ma, and T. Endoh, “Bridging Artificial Intelligence and Devices: Power Reduction Method of Non-volatile Devices with Error-resilient Deep Neural Networks,” IEEE Transactions on Magnetics, pp.1-9, Oct. 2023. DOI：10.1109/tmag.2023.3321878.

[6] T. Li, L. Zhang, and T. Endoh, “Small Area and High Throughput Error Correction Module of STT-MRAM for Object Recognition Systems,” IEEE Transactions on Industrial Informatics, 2024 (in press).

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 during problem solving, within which participants were allowed to request hints. To estimate when participants needed hints, we used a machine learning techinique with face features. The results showed that face features a few seconds before hint request have information of the mental state to seek hints.

[Staff]

Satoshi Shioiri, Project Leader, Professor

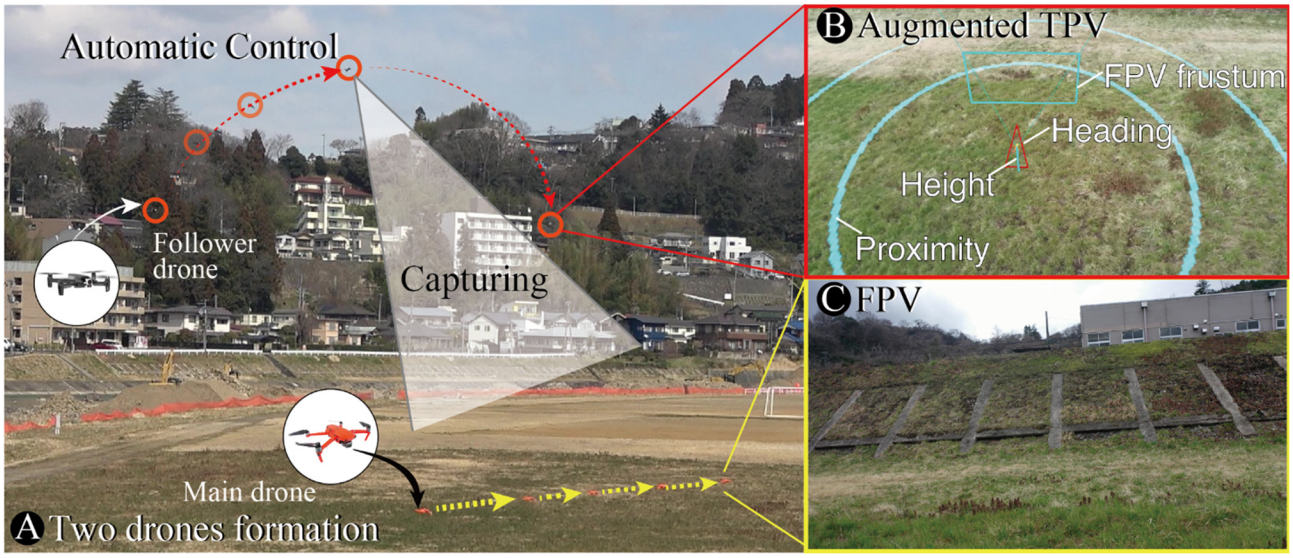
[Profile]

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] Wang, GY., Nagata, H., Hatori, Y., Sato, Y., Tseng, C.H., Shioiri, S. Detecting learners' hint inquiry behaviors in e-learning environment by using facial expressions, Proceedings of the Tenth ACM Conference on Learning@ Scale, 2023
[2] Miao, R., Kato, H., Hatori, Y., Sato, Y., Shioiri, S. Use of facial expressions to estimate level of attention while watching video lectures, Journal of Vision 23 (9), 4726-4726, 2023
[3] Shioiri, S., Nagata, H., Sato, Y., Hatori, Y. Prediction of preference judgments of face images using facial expressions and EEG signals, Journal of Vision 23 (9), 5063-5063, 2023

Exploratory Research Division
Drone Utilization Technologies to Realize a Symbiotic Society



BirdViewAR overview with two drone formations

Yoshifumi Kitamura, Professor (Project Leader)

[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

Noriharu Suematsu, Professor (Project Leader)
Takashi Shiba, Specially appointed Professor
Tomoyuki Furuichi, Assistant Professor

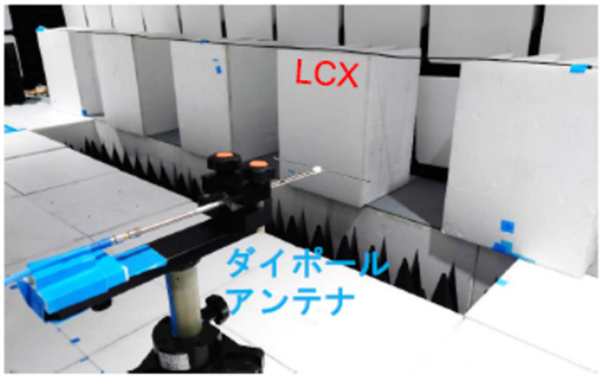


Fig.1: Leaky coaxial cable (LCX)

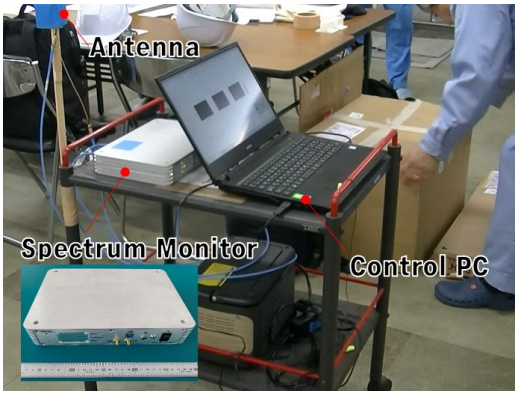


Fig.2: Factories Radio Environment Monitoring

[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.

Fig.1 shows LCX communication evaluation setup system for smart factories. We evaluated the effect of shadowing in a situation where a metal obstacle (e.g. wall) is placed near the antenna. Fig.2 shows factories radio environment monitoring in smart factories using developed real-time spectrum monitor. We monitored the radio wave environment in factories and evaluated the channel occupancy rate.

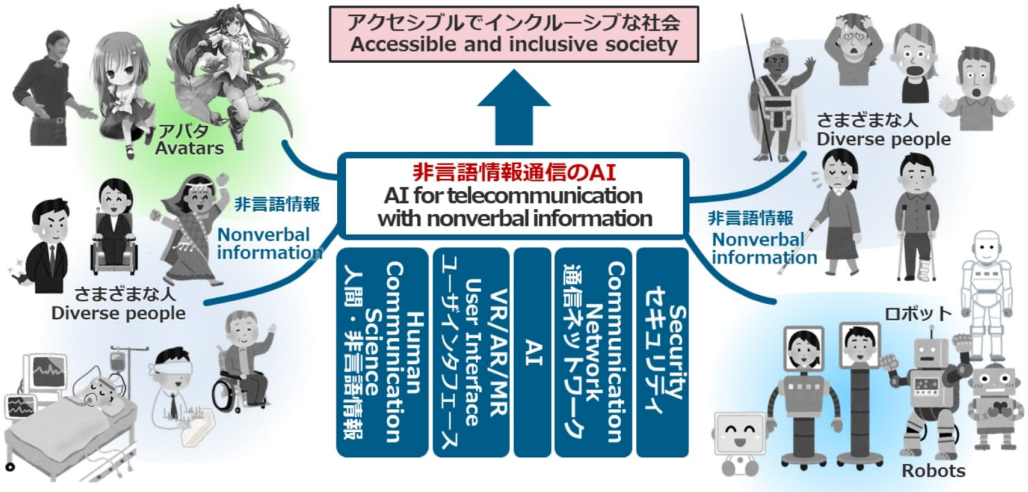
[Papers]

[1] E. Nagahari, T. Furuichi, T. Shiba, N. Suematsu, "A study on shadowing caused by a metallic object placed near LCX antenna of 920MHz-band," 2023 XXXVth General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS), Sapporo, Japan, 2023.

Interdisciplinary ICT Research Center for Cyber and Real Space

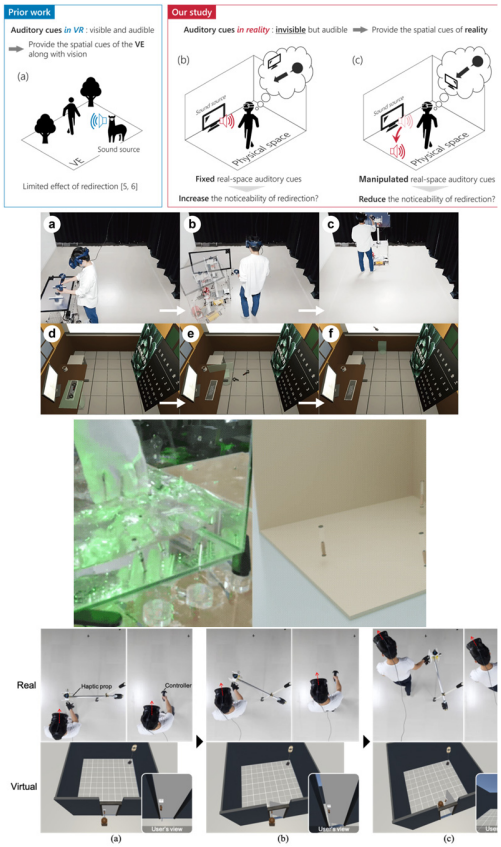
In future telecommunications, it is expected that people will be able to communicate with each other in the cyber/virtual space with objects and information from the physical/real space they are located.

The successful key to realize such rich telecommunication is to unlock “communication with nonverbal information” by appropriately conveying the subtleties of “non-spoken signals,” which plays an important role in our daily interpersonal understanding. When AI for “verbal information” has become a useful tool to transcend the barriers of language differences, we hope creating AI for “nonverbal information” to build an accessible and inclusive society that accommodates diversities in physical competences, cultures, gender, etc.
We start to conduct research and development of “telecommunication with nonverbal information” through interdisciplinary collaboration. We will synergize basic and applied AI research, networks and security, human sciences (psychology, brain sciences), human-computer interactions, and VR/AR/MR communication technologies, to impact the society with the research results.



Enrich Telecommunication with Nonverbal Information

[Research Target and Activities]



1. Visual-Auditory Redirected Walking using Auditory Cues in Real/Physical Space
   We investigated the effects of sounds emitted from the real/physical space on the perception of Redirected Walking, rather than sounds in the virtual/cyber space [1].
2. Endless Cyber/Virtual Space, Roaming around in a Small Room
   We developed RedirectedDoors+, which built upon an existing visuo-haptic door-opening redirection technique, allows participants to subtly manipulate the walking direction while opening doors in VR, guiding them away from real walls [2].
3. Sharing Interactions with Real/Physical Space in Cyber/Virtual Space
   We have harnessed the power of deep reinforcement learning to replicate the flow of water when disturbed. Replicating this agitated liquid motion, as it is known, allowed them to recreate water flow in real time based on only a small amount of data from real water. The technology opens up the possibility for virtual reality interactions involving water [3].
4. A Robotic Touch Surface for Supporting Mid-air Planar Interactions in Room-Scale VR
   We propose a robotic touch surface that can automatically reposition itself to physically present a virtual planar input surface to users and to permit them to achieve accurate and fatigue-less input while walking around a virtual room [4].

[Papers]

[1] Kumpei Ogawa, Kazuyuki Fujita, Shuichi Sakamoto, Kazuki Takashima, Yoshifumi Kitamura, Exploring Visual-Auditory Redirected Walking using Auditory Cues in Reality, IEEE Transactions on Visualization and Computer Graphics, 2023. https://doi.org/10.1109/TVCG.2023.3309267

[2] Ryota Gomi, Kazuki Takashima, Yuki Onishi, Kazuyuki Fujita, and Yoshifumi Kitamura. UbiSurface: A Robotic Touch Surface for Supporting Mid-air Planar Interactions in Room-Scale VR, Proceedings of the ACM on Human-Computer Interaction, Volume 7, Issue ISS, Article No.: 443, pp. 376–397, 2023 https://doi.org/10.1145/3626479

[3] Kinfung Chu, Jiawei Huang, Hidemasa Takana, and Yoshifumi Kitamura. Real-Time Reconstruction of Fluid Flow under Unknown Disturbance, ACM Transactions on Graphics, Volume 43, Issue 1, Article No. 4, pp 1–14 https://doi.org/10.1145/3624011

[4] Yukai Hoshikawa, Kazuyuki Fujita, Kazuki Takashima, Morten Fjeld, Yoshifumi Kitamura: RedirectedDoors+: Door-Opening Redirection with Dynamic Haptics in Room-Scale VR, IEEE Transactions on Visualization and Computer Graphics, 2024. https://ieeexplore.ieee.org/document/10466477

Co-Creation Research Center

Furukawa Electric x Tohoku Univ. Co-Creation Research Center for Photonics Integration

＜Aims＞

Our Co-Creation Research Center aims to create innovative new technologies driven by novel ideas and to develop highly specialized human resources through integration and collaboration between Furukawa Electric's materials processing capabilities and Tohoku University's comprehensive solution capabilities toward challenges in our society. The collaboration is based mainly in the field of photonics, which plays a vital role in our future advanced information society infrastructure. Specifically, we are exploring new research frontiers and promoting joint research toward innovative new technologies with a diverse impact, such as the integration of mobility, energy, and information, which will contribute to the realization of a sustainable society where people can enjoy safe, peaceful and rewarding life. In addition, through co-creation and collaboration between the two organizations, we will contribute to the development of human resources with advanced engineering backgrounds and the ability to practice integrative and creative thinking with different fields.

＜Results in 2023＞

In order to start co-creation in the field of photonics, we held a technical conference between members of our Co-Creation Research Center and Furukawa Electric. Through these activities, we were able to have many exchanges in the field and start three co-creation projects.

Even in fields other than photonics, we were able to make a lot of opportunities for dialogue between various departments of Tohoku University and Furukawa Electric. From these opportunities, we were able to start three co-creation projects.

The co-creation projects, which began in 2023, are currently in the process of coordinating contracts for joint research or academic guidance. In 2024, we plan to share goals and move forward with efforts to solve their technological and social challenges.

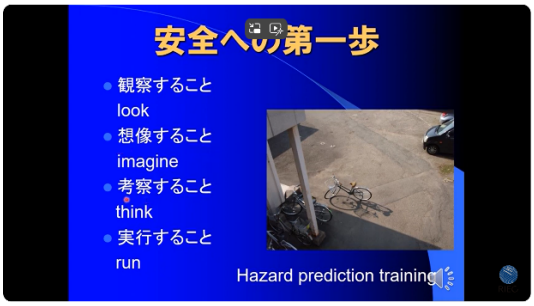
＜Member＞

Specially Appointed Professor　Michihiro Shimada

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.

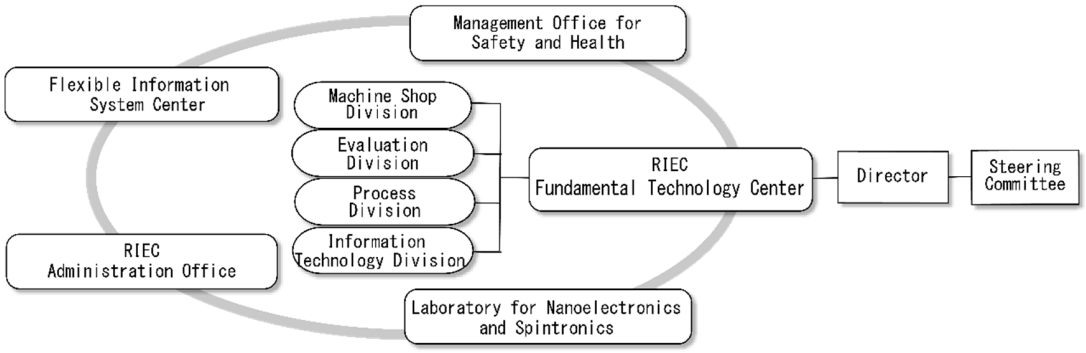
[Staff]

(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 (-2023 Nov.), Hitoshi Shoji (2024 Mar.-)

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 87 machining products. About 11% of the requests were from outside the institute.

2. Evaluation Division

23 laboratories and 6 external research institute and company utilized the evaluation and measurement apparatuses for shared usage (the utilization time was 2,117 hours). Technical assistance on the use of liquid helium was provided for 2 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, 381 Electron-beam lithography products, 31 photomasks and 18 commissioned analyzes such as focused ion beam processing and analysis 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 TSUKIMOTO, 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.

[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 2023, 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 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. We also organized a special session in the 2023 International Symposium on Nonlinear Theory and Its Applications. Furthermore, we actively cooperated with the JST CREST Sato project for proposing the Yamamoto project of Grant-in-Aid for Transformative Research Areas (A). As a result, the proposal was granted.

Division for the Establishment of Frontier Sciences

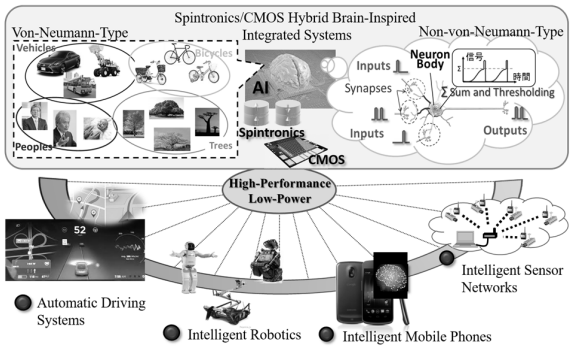
Spintronics/CMOS Hybrid Brain-Inspired Integrated Systems

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]

This research includes the integration of spintronics engineering, CMOS semiconductor integrated circuit engineering, and neuroscience to develop an innovative interdisciplinary field of engineering that covers devices, circuits, architecture, and software. The objective is to develop innovative computing systems that mimic the brain's functionality, enabling advanced information processing and decision-making while maintaining high efficiency and low power consumption. More precisely, the research use two different approaches to verify the funcationality of brain-inspired VLSI: von Neumann and non-von Neumann architectures. It focuses on enhancing our understanding of spintronics-CMOS hybrid devices and developing theories on circuit and architecture design based on spintronics-CMOS integration, brain-inspired CMOS integrated circuits, and AI computing. This will facilitate the realization of highly functional and ultra-low-power, non-volatile, brain-inspired object detection systems targeting applications such as autonomous operation and intelligent robotics.



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

The project focused on leveraging the error resiliency of neural networks to further reduce the power consumption of non-volatile devices. Specifically, it involves developing new algorithms suitable for low-power operation by using the nonlinear relationship between switching current and switching probability in non-volatile devices and the fault tolerance of neural networks. This aims to enhance both energy and computational efficiency. Additionally, the project focuses on improving the throughput of ECC modules, which includes optimizing ECC algorithms, strengthening parallel processing, and enhancing data processing efficiency. The progress of these two research achievements and the associated research results this year are presented as follows:

1. **Integration of deep neural networks with non-volatile memory devices to improve energy efficiency in edge computing.**

   We are exploring methods to reduce power consumption by bridging the fault tolerance of neural networks with the non-linear switching properties of non-volatile devices. We theoretically deduce the connection between the fault tolerance of DNNs and the switching current of non-volatile devices, and we experimentally demonstrate its effectiveness in lowering power consumption without compromising the accuracy of DNNs, by incorporating random errors into the parameters of low 8-bit DNNs. The experimental results show that flipping a random 20%

of the binaries can reduce power consumption by 5.63% and flipping 100% can save 34.84% of energy. Also, adding the error map of six real STT-MRAM chips, which have a top error rate of 0.00868, to the low 8-bit settings of DNNs doesn't change their accuracy in a situation where there are 100% chances of switching (the largest loss is 0.00067). The impact on industrial applications is negligible, as evidenced by the reductions in top-1 and top-5 accuracy of MobileNet, which are 0.000355, 0.00079, 0.000670, and 0.000310, respectively.

2. **Enhanced object recognition using ECC-enabled STT-MRAM.**
   The code length and correction capabilities of the BCH code are optimized, considering memory redundancy and computational complexity. The correction performance of the proposed ECC module is validated based on the actual operating measurements of STT-MRAM chips, and the implementation results demonstrate a small area of $18.27\ k\ \mu m^2$ with 64-bit high throughput and a 5.76 ns read delay. The experimental results indicate that if the bit error rate of STT-MRAM is below 2×10^{-3}, it does not affect the recognition accuracy of neural networks. These experimental results show that the ECC module is suitable for most manufactured STT-MRAM chips and can be integrated into object detection systems, representing a significant milestone for research aimed at diverse applications of brain-inspired processors in edge computing, potentially bringing innovative possibilities.

[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). He is an IEEE Fellow (2023).

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, L. Zhang, Y. Ma and T. Endoh, "Bridging Artificial Intelligence and Devices: Power Reduction Method of Non-volatile Devices with Error-resilient Deep Neural Networks," in IEEE Transactions on Magnetics, October 4, 2023. Early Access. doi: 10.1109/TMAG.2023.3321878.

[2] L. Zhang, T. Li and T. Endoh, "Small Area and High Throughput Error Correction Module of STT-MRAM for Object Recognition Systems," in IEEE Transactions on Industrial Informatics, February 26, 2024. Early Access. doi: 10.1109/TII.2024.3362373.

Center for Science and Innovation in Spintronics (CSIS)

＜About the Center＞

Establishment：January 30, 2018

Organization：Director: Shunske Fukami (Professor of RIEC)
Number of academic members: 59
(including 10 full-time, 35 concurrent and 14 guest 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 2023＞

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

  Excellent 6 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, 8 persons from foreign countries, were employed as full-time researchers to promote collaborations with researchers of domestic and foreign institutions. The Core Research Cluster for Spintronics Award was launched to honor early-career researchers who have produced outstanding academic achievement and/or industrial applications in Spintronics.

- **Promoting international academic exchange**

  The laboratory for international collaboration with the University of Chicago was operated continuously. The 7th International Symposium for the Core Research Clusters for Materials Science and Spintronics was held in November and December, 2023. The following international meetings were also co-sponsored or supported by CSIS:

  - 2nd Online RIEC International Workshop on Spintronics (April, 2023)
  - 2023 Spintronics Workshop on LSI (June, 2023)
  - Spintronics and Quantum Transformation Workshop (August, 2023)
  - Tohoku-Warsaw Workshop for Spintronics (November, 2023)
  - 2nd International Workshop of Spin/Quantum Materials and Devices (November, 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: 77 (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 FY2022＞

CIES has managed the “CIES consortium” which consists of industry–academic collaborations, major national projects (MEXT X-nics, NEDO Post 5G, NEDO AIC, JSPS Core-to-Core, JAXA TansaX, MEXT Power Electronics, CAO SIP 3rd) and regional collaboration projects. We have promoted the development of core technologies related integrated electronics from material, equipment, devices and system to include spintronics, AI hardware, and power electronics 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" by METI in 2020. 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 2023, Japan's "Semiconductor/Digital Industrial Strategy" was revised, and "advanced technology development (spintronics technology) at academia-based centers" was positioned as a goal/strategy. At the G7 Hiroshima Summit, the “the U.S.-Japan University Partnership for Workforce Advancement and Research & Development in Semiconductors (UPWARDS) for the Future” was concluded. In response to these policies and agreements, we have been working to strengthen innovative semiconductor research and development, manufacturing, supply chains, and human resource development through collaboration between industry and U.S. and Japanese universities.

CIES has developed a variety of innovative technologies with world-first 300mm wafer process line and facilities operated by the university for prototype manufacturing and characterizing spintronics integrated circuits compatible with world-class companies, and has made progress in developing IoT and AI systems that require ultra-low power consumption. Specifically, we have succeeded in developing a low power consumption MRAM technology that has data retention for more than 10 years and rewrite tolerance that reaches 1 trillion times with the integrated technology of the single digit nanometer generation. We have demonstrated data retention at 260°C and over 10 million rewrites during manufacturing of cutting-edge microcontrollers using a new 6-layer interface perpendicular ferromagnetic magnetic tunnel junction device. This achievement opens the door to higher performance and larger capacity embedded nonvolatile memory for cutting-edge single-digit nm generation microcontrollers. Six new institutions have joined the MEXT Initiative to Establish Next-generation Novel Integrated Circuits Centers (X-NICS) "Innovative spintronics X semiconductor research hub" adopted in 2022. We are promoting the creation of innovative low-power semiconductors and the development of highly skilled human resources. In power electronics technology, we will advance the advancement of power electronics circuit technology and power module technology through MEXT INNOPEL (Innovative Power Electronics Technologies), which was adopted in 2021, and will develop compact power supplies for EV drive inverters and data centers, and contributed to the improvement of performance and performance. Furthermore, we proceeded with R&D of a next-generation circuit system that takes advantage of the low-loss, high-frequency operation features of GaN on Si power devices, and investigated the optimal devices and passive components for the circuit system. As a result, we have obtained the prospect of achieving higher efficiency and higher power density in next-generation circuit systems. Utilizing the three core technologies, we aim to develop system beneficial to AI/IoT/DX, which is indispensable for realizing carbon neutrality and requires ultra-low power consumption. Utilizing the three core technologies, 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 sixth 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. Through our participation in the TOHOKU Study Group on Design of Semiconductor and Electronics Industry, which was launched in June 2022, we have been working to strengthen the foundations of semiconductor and other related industries, develop human resources, and strengthen the supply chain, while collaborating with related organizations such as industry, universities, technical colleges, and government.

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: Nobuyuki Sakai (Professor, Graduate School of Arts & Letters/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, of International Cultural Studies, Graduate School 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 2023＞

1. To establish a successor organization of AIYotta, which aiming at the further development of data science interdisciplinary research with a view to hardware was approved, we requested a budget for the government, and succeeded to have support for the organization, Advanced Instituted of So-Go-Chi (convergence knowledge) Informatics to start in 2024.
2. We supported 4 projects from 19 interdisciplinary projects supported in 2022, which lead the new information science, which can manage the quality of information as well as the information amount and select important information appropriately.
3. We co-organized a RIEC international symposium “Tohoku U - NTU Symposium: When AI Meets Human Science," International Workshop on Emerging ICT, and HIP Research meeting of IEICE.

Graduate Program in Spintronics (GP-Spin)

＜Overview＞

Establishment：April 1, 2015

Organization：Graduate Program in Spintronics (GP-Spin) Program Director: Takafumi Sato
(Graduate School of Science, Professor)
Program members: 12 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 Netherlands), 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 FY2023＞

In FY 2023, the following academic meetings sponsored or co-sponsored by GP-Spin were held.
- The 1st Young Scholars Workshop in Spintronics (July, 2023)
- GP-Spin Session, The 32nd Joint-Interlaboratory Workshop on Nano-Magnetics at Korea University (July, 2023)
- The 1st Workshop on the Chicago-Tohoku Quantum Alliance (October, 2023)
- The 7th Symposium for the Core Research Clusters for Materials Science and Spintronics and the 6th Symposium on International Joint Graduate Program in Materials Science and Spintronics (November-December, 2023)
- GP-Spin Session, The 34th Joint-Interlaboratory Workshop on Nano-Magnetics in Sendai (February, 2024)
- Tohoku-Lorraine Mini Workshop 2024 (February, 2024)

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 2023＞

In FY2023, 16 students completed the 5-year integrated education curriculum of the AIE-WISE program for AI Electronics. The program received high ratings from on-site visits by a program officer (PO) and visits by an external evaluation committee. The Project Based Learning (PBL) courses, which are unique to the AIE-WISE program, were delivered in a face-to-face format in FY2023. After the end of the course, a symposium was held in which students presentated 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 sixth year, and 31 new students (12 new M1 students, 13 new M2 students, and 6 new D1 students) were selected.

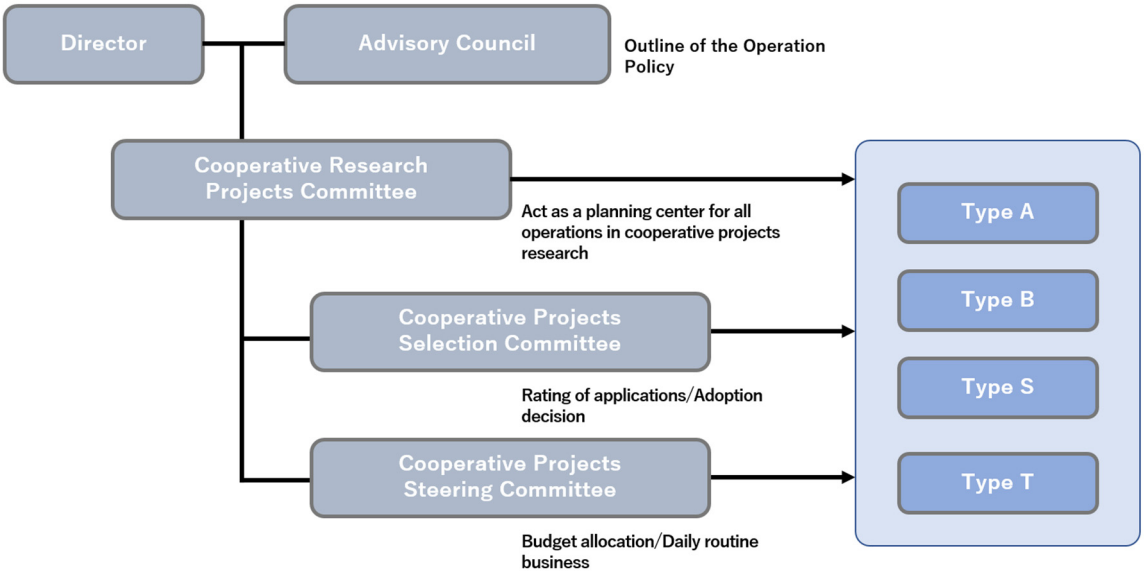
4. Nation-wide Cooperative Research Projects

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 2023

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
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/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**
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**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
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 for the 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,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**
R03/A26	Quantum research based on integration of experimental, theoretical and data science	**FUKUHARA Takeshi** Center for Quantum Computing, RIKEN	**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/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**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R03/A31	Research on the formation of a gravity observation network using optical communication technologies and the monitoring of volcanic activities	**KASAI Keisuke** RIEC, Tohoku University	**KASAI Keisuke**
R03/A32	Hardware Technology for Brain Computing and its Application to Edge Computing	**SATO Shigeo** RIEC, 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**
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/A08	High-frequency response of submicron-sized magnetic materials with asymmetric magnetic vortex structure	**KODA Tetsunori** Department of Electronic Mechanical Engineering, National Institute of Technology, Oshima College	**ISHIYAMA Kazushi**
R04/A09	Development of efficient magnetization-switching devices using transition metal compounds	**SHINJI Isogami** Research Center for Magnetic and Spintronic Materials, National Institute for Materials Science	**SHIRAI Masafumi**
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 High-Frequency High-Power Devices and Circuits for Post-5G Base Stations	**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/A16	Study on application of facial expression analysis to remote medical care	**SATO Yoshiyuki** Advanced Institute for Yotta Informatics, Tohoku University	**SHIOIRI Satoshi**
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** RIEC, Tohoku University	**CHENG Miao**
R04/A21	Propagation directivity of wireless body area network	**AKIMOTO Kohei** Department of Intelligent Mechatronics, Faculty of Systems Science and Technology, Akita Prefectural University	**SUEMATSU Noriharu**
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**
R05/A01	Study on graphene emitter	**NAGASE Masao** Institute of Post-LED Photonics, Tokushima University	**OTSUJI Taiichi**
R05/A02	Development of Fundamental Technology of Materials and Processes for New Group-IV Semiconductor Nanoelectronics	**SAKURABA Masao** RIEC, Tohoku University	**SAKURABA Masao**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R05/A03	Development of a sensitive TiO2 nanotube gas sensor	**KIMURA Yasuo** School of Engineering, Tokyo University of Technology	**HIRANO Ayumi**
R05/A04	Development of intraluminal NMR probe for high magnetic field MRI	**MATSUNAGA Tadao** Faculty of Engineering, Tottori University	**SUEMATSU Noriharu**
R05/A05	Fundamental Survey on Measurement of Intraoral Bite Force Using Inverse Magnetostrictive and Magneto-Optical Effects	**ISOGAI Ryosuke** R&D Department, Seiko Future Creation Inc.	**GOTO Taichi**
R05/A06	2D van der Waals quantum materials for efficient charge-spin conversion	**Singh Ravi Prakash** Department of Physics, Indian Institute of Science Education and Research Bhopal	**FUKAMI Shunsuke**
R05/A07	Japan-Russia International collaborative research of new designs of high-power large-area photoconductive antenna-emitters	**DMITRY Ponomarev** Laboratory of high-power microwave and mm-wave applications, Institute of ultra high frequency semiconductor electronics of Russian academy of sciences	**OTSUJI Taiichi**
R05/A08	Investigation of physical structure model of high-k/Ge interface affected by process temperatures	**OTANI Yohei** Department of Mechanical and Electrical Engineering, Faculty of Engineering, Suwa University of Science	**SATO Shigeo**
R05/A09	Study on plasmonic nanodevices based on two-dimensional materials	**UCHINO Takashi** Department of Electrical and Electronic Engineering, Faculty of Engineering, Tohoku Institute of Technology	**OTSUJI Taiichi**
R05/A10	Current-induced orbital effects in magnetic heterostructures	**DUTTAGUPTA SAMIK** Condensed Matter Physics Division, Saha Institute of Nuclear Physics	**FUKAMI Shunsuke**
R05/A11	survey of over100GHz direct digital transceiver technology	**SUEMATSU Noriharu** RIEC, Tohoku University	**SUEMATSU Noriharu**
R05/A12	Study on optimization design of milli-meter wave devices and transmission lines	**ITOH Keiichi** Department of Electrical and Information Engineering, National Institute of Technology, Akita College	**SUEMATSU Noriharu**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R05/A13	New generation of 2d material based devices for terahertz technology	**MEZIANI Yahya Moubarak** Dept. Fisica Aplicada, Salamanca University	**OTSUJI Taiichi**
R05/A14	Collaborative evaluation of non-verbal communication solutions	**Benjamin WATSON** Department Computer Science, North Carolina State University	**CHENG Miao**
R05/A15	Practice of experiential on-the-job training using VR equipment in the field of occupational health	**IROKAWA Toshiya** Graduate School of Medicine, Tohoku University	**KITAMURA Yoshifumi**
R05/A16	Research on dynamic VR/AR workspaces for inducing physical movements	**TAKAHARA Ryo** TATAMI inc.	**FUJITA Kazuyuki**
R05/A17	Auditory influences on saccadic suppression	**Hiu Mei CHOW** Psychology, St. Thomas University	**TSENG Chia-huei**
R05/A18	Constructive analysis of brain computing based on multicellular networks	**TANII Takashi** Faculty of science and engineering, Waseda university	**YAMAMOTO Hideaki**
R05/A19	Expansion of nonlinear complex systems theory to spatiotemporal systems and its applications	**HORIO Yoshihiko** RIEC, Tohoku University	**HORIO Yoshihiko**
R05/A20	Characterization of microstructure and properties of high-performance soft magnetic iron alloys	**SUZUKI Shigeru** Micro System Integration Center, Tohoku University	**ISHIYAMA Kazushi**
R05/A21	New development of multicellular neurobiocomputing	**KAMIYA Haruyuki** Graduate School of Medicine, Hokkaido University	**YAMAMOTO Hideaki**
R05/A22	Motion Unit: A data-driven study on bodily emotion expressions	**FUJIWARA Ken** Department of Psychology, National Chung-Cheng University	**CHENG Miao**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R05/A23	Research of the fundamental technologies of edge computing and edge-assisted smart systems for smart city	**SHAO Xun** Department of Electrical and Electronic Information Engineering, Toyohashi University of Technology	**HASEGAWA Go**
R05/A24	Research on Autopoietic Service Platform Supporting Smart Society	**KITAGATA Gen** Department of English, Morioka University	**HASEGAWA Go**
R05/A25	High precision phase locking technologies for quantum key distribution	**HIRANO Takuya** Department of Physics, Gakushuin University	**YOSHIDA Masato**
R05/A26	Investigating the impact of physical activity in virtual reality on cognitive performance	**Tag Benjamin** Department of Human-Centred Computing/Data Visualisation and Immersive Analytics Lab, Monash University	**KITAMURA Yoshifumi**
R05/A27	Research on online text analysis using machine learning	**ZABIR Salahuddin Muhammad Salim** Department of Creative Engineering, National Institute of Technology, Tsuruka College	**HASEGAWA Go**
R05/A28	Deep learning based object detection for ultra high resolution image sensing	**Matsumura Tetsuya** College of Engineering, Nihon University	**OTSUJI Taiichi**
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, Yhe University of Tokyo	**SATO Shigeo**
R03/B06	Theory and implementation for control-less wireless power supply systems	**SEKIYA Hiroo** Graduate School of Engineering, Chiba University	**HORIO Yoshihiko**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R03/B07	A Study on Adaptive Workspaces in the After-Corona Era	**FUJITA Kazuyuki** RIEC, 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 Technology, 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/B12	Empirical Research on dic Ubiquitous Computing Systems	**ISHIDA Shigemi** School of Systems Information Science, Department of Media Architecture, Future University Hakodate	**HASEGAWA Go**
R04/B03	Nanomaterial production by using novel gas-phase process and its application to high-performance devices	**UCIDA 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	**MURAYAMA Hiromi** Sales & Marketing Division, Sales Promotion Department, Pacific Convention Plaza Yokohama	**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**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
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**
R04/B11	An Inter-personal Dimension of MA: Behavior, Physiology, and Engineering	**TSENG Chia-huei** RIEC, Tohoku University	**TSENG Chia-huei**
R05/B01	Design of Borderless Wireless Networks for Digital Twin Society	**SATO Koya** Artificial Intelligence eXploration Research Center, The University of Electro-Communications	**SUEMATSU Noriharu**
R05/B02	Integrated Design of Wireless Communication System and Hardware in the Massive Connect IoT Era	**KAMEDA Suguru** Research Institute for Nanodevices, Hiroshima University	**SUEMATSU Noriharu**
R05/B03	Highly Functional Coherent Communication and Measurement Systems Integrating Lightwave and Microwave	**INOUE Takashi** Platform Photonics Research Center, National Institute of Advanced Industrial Science and Technology	**HIROOKA Toshihiko**
R05/B04	Millimeter-wave and Terahertz Wave Technologies and Applications for 6G System	**SANADA Atsushi** Graduate School of Engineering Science, Osaka University	**SUEMATSU Noriharu**
R05/B05	Amplification and Attenuation Effects on Actions and Emotions in Human-Computer Interaction	**NAKAKOJI Kumiyo** Department of Media Architecture, Future University Hakodate	**KITAMURA Yoshifumi**
R05/B06	Physical / Virtual Presentations	**Mario DOULIS** New Media Department, Merz Akademie Stuttgart	**KITAMURA Yoshifumi**
R05/B07	Integration process of multi-sensory information in self-motion perception	**SAKURAI Kenzo** Faculty of Liberal Arts, Tohoku Gakuin University	**SAKAMOTO Shuichi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R05/B08	Study of methods for guiding a flock of crows	**TSUKAHARA Naoki** CrowLab Inc	**KITAMURA Yoshifumi**
R05/B09	Development of device modules using 3D printer and its application	**MANABE Hiroyuki** Department of Computer Science and Engineering, Shibaura Institute of Technology	**TAKASHIMA Kazuki**
R05/B10	Spatial Informatics by Understanding Human's Physical and Spatial Behaviors	**YAMAMOTO Goshiro** Kyoto University Hospital, Kyoto University	**TAKASHIMA Kazuki**
R05/B11	Development and control of artificial cell membrane systems for measuring membrane protein functions based on semiconductor microfabrication technology and nanomaterial functions	**TERO Ryugo** Department of Environmental and Life Sciences, Toyohashi University of Technology	**HIRANO Ayumi**
R05/B12	Elucidation of tactics mechanism between sheep and sheepdog in shepherding phenomenon	**TSUNODA Yusuke** Graduate School of Engineering, Osaka University	**KANO Takeshi**
R05/B13	Theoretical studies on memory and learning in neural networks	**IKEGUCHI Tohru** Faculty of Engineering, Tokyo University of Science	**HORIO Yoshihiko**
R05/B14	Research on direct manipulation interface for document-based videos	**FUJITA Kazuyuki** RIEC, Tohoku University	**FUJITA Kazuyuki**
R05/B15	Research on fundamental technologies related to human and social sensing and intervention	**ARAKAWA Yutaka** Graduate School of Information Science and Electrical Engineering, Kyushu University	**OTSUJI Taiichi**
R05/B16	Study on applications using head-gaze tracking technique with a smartphone	**FUJITA Kazuyuki** RIEC, Tohoku University	**FUJITA Kazuyuki**
R05/B17	International Research Collaboration of Brainware-LSI-Oriented Emerging Circuits/Systems	**HANYU Takahiro** RIEC, Tohoku University	**HANYU Takahiro**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R05/S01	Establishment for innovative coherent wave technology and its applications	**AOKI Toru** Research Institute of Electronics, Shizuoka University	**YASAKA Hiroshi**
R03/SI01	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	**MATSUURA Yuji** 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** RIEC, 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**
R04/T06	**Research presentation on theory and applications of system control** Next generation biodevices based on bio-nanoelectronics	**HIRANO Ayumi** RIEC, 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	**HOMMA Naofumi** RIEC, Tohoku University	**HOMMA Naofumi**

Grant Number	Title of Research	Principal Investigator	Research Collaborator of RIEC
R04/T09	**Technical committee for ultrasonic electronics** Research presentation on basics and applications of ultrasound	**YOSHIZAWA Shin** Graduate School of Engineering, Tohoku University	**SAKAMOTO Shuichi**
R04/T10	**Brainware Research Project** Toward Life-like Intelligent Information Processing System	**ISHIGURO Akio** RIEC, Tohoku University	**ISHIGURO Akio**
R04/T11	**Biocybernetics and Bioinformatics** Analysis and modelling of biological signals	**SHIOIRI Satoshi** RIEC, 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** RIEC, 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 FY2023)

No	Title	Date
125	The 20th International Workshop on Emerging ICT	Oct. 16-18,2023
126	20th RIEC International Workshop on Spintronics	Nov. 28 - Dec. 1,2023
127	RIEC International Symposium on Enriching Telecommunication and Nonverbal Information	Jan. 26-27,2024
128	The 12th RIEC International Symposium on Brain Functions and Brain Computer	Feb. 27-28,2024
129	The 14th International Workshop on Nanostructures and Nanoelectronics	Mar. 5-6,2024

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 University of Singapore (Singapore)
- National Taiwan University (Taiwan)
- Swiss Federal Institute of Technology, Lausanne (Swiss)
- National Chung Cheng University (Taiwan)
- 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 Thonburi (Thailand)
- Chemnitz University of Technology (Germany)
- University College London, UCL (U.K.)
- The University of Melbourne (Australia)
- University of Regensburg (Germany)
- Carl von Ossietzky University of Oldenburg (Germany)
- University of Lorraine (France)
- 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	Scientific Reports
2	Proceedings of the ACM on Human-Computer Interaction (PACMHCI) Editor
3	Auditory Perception & Cognition
4	Nonlinear Theory and Its Applications, IEICE
5	IEICE Electronics Express

Recent international conferences programmed by a staff in RIEC

1	ICOOPMA: International Advisory Committee member, International Conference on Optical, Optoelectronic and Photonic Materials and Applications; IAC (Int. Advisory Comm.), 9th in Ghent, Belgium, July 3 - 7, 2022; IAC, 10th, in Pardubice, Czech, June 23-28, 2024
2	CIMTEC: International Conferences on Modern Materials & Technologies; International Advisory Board member; Montecatini Terme (near Florence), Italy, June 19-23, 2020, June 2021, June 20-29, 2022.(postponed due to covid19)
3	SPIE Photonics-EU: SPIE International Conference on Photonics Europe, Conference on Terahertz Photonics; TPC member; Strasbourg, France, Apr. 1-2, 2020, Apr. 2021, Apr. 3-7, 2022. (postponed due to covid-19)
4	RPGR: International International Conference on Recent Progress in Graphene and Related 2D Materials Research; IAB (Int. Advisory Board) Chair, member; IAB Chair, LOC Co-Chair, in Matsue, Japan, Oct. 6-10, 2019; IAB Chair, in Seoul, Korea (Online), Oct. 10-15, 2021; IAB member, in Taipei, Taiwan, Nov. 13-16, 2022
5	2DM: International Congress on Graphene, 2D Materials and Applications; TPC member, Sochi, Russia, Sept. 30-Oct. 4, 2019
6	IRMMW-THz: International Conference on Infrared, Millimeter, and Terahertz Waves; IOC (International Organizing Committee) member; 2016~; IOC, TPC, 46th in Chengdu, China, Aug. 29-Sept. 3, 2021; IOC, TPC, 47th in Delft, Netherland, Aug. 29 - Sept. 2,2022; IOC, TPC, 48th in Montreal, Canada, Sept 17-11, 2023
7	META 19: The 10th International Conference on Metamaterials, Photonic Crystals and Plasmonics, Lisbon, Portugal, July 22-25, 2019; Special Session Organizer
8	TWHM: Topical Workshop on Heterostructure Microelectronics; TPC member; 2003~; TPC, in Toyama, Japan, April 26-29, 2019; TPC, in Hiroshima, Japan, Aug. 29-Sept. 1, 2022
9	RJUSE: Russia-Japan-USA-Europe Symposium on Fundamental & Applied Problems of Terahertz Devices & Technologies; ISC (International Steering Committee) Chair, 2017~; Nizhny Novgorod, Russia, Jul. 8-11, 2019.
10	CSW/ISCS: Compound Semiconductor Week / International Symposium on Compound Semiconductors; Program Sub-Committee member, in Matsue, Japan, May 19-23, 2019.
11	TeraTech: International Symposium on Terahertz-Related Devices and Technologies; General Chair, and ISC (Int. Steering Comm.) Chair, 10th in Aizuwakamatsu, Japan, Sept. 4 - 8, 2023
12	SPIE Optics+Photonics 2022, Conferene on Terahertz Emitters, Receivers, and Applications XIV (OP412); TPC member, SanDiego, CA, USA, Aug. 20-24, 2023.

13	RJUSE 2019: TPC member, Russia-Japan-USA-Europe Symposium on Fundamental & Applied Problems of Terahertz Devices & Technologies, Nizhny Novgorod, Russia, Jul. 8-11, 2019.
14	RJUSE 2020: Chair, Russia-Japan-USA-Europe Symposium on Fundamental & Applied Problems of Terahertz Devices & Technologies, Sendai, Japan, Nov. 2-5, 2020.
15	TeraTech: International Symposium on Terahertz-Related Devices and Technologies; LOC (Local Org. Comm.) Co-Chair, 10th in Aizuwakamatsu, Japan, Sept. 4 - 8, 2023
16	SSDM 2022: International Conference on Solid State Devices and Materials; Area 4 Technical Program Committee member, in Chiba, Japan, Sept. 26 - 29, 2022.
17	SSDM 2023: International Conference on Solid State Devices and Materials; Area 4 Technical Program Committee member, in Nagoya, Japan, Sept. 5 - 8, 2023.
18	IEEE Virtual Reality and 3D User Interface 2023, Program committee
19	ACM Symposium on Virtual Reality Software and Technology 2022, Program Co-Chair
20	ACM Symposium on Virtual Reality Software and Technology, Steering Committee Chair
21	ACM CHI Conference on Human Factors in Computing System, Steering Committee
22	International Conference on Artificial Reality and Telexistence, Steering Committee
23	The 2022 International Symposium on Nonlinear Theory and Its Applications, General Co-chair
24	The 2020 International Symposium on Nonlinear Theory and Its Applications, General Vice-Chair
25	13th International WorkShop on New Group IV Semiconductor Nanoelectronics, RIEC, Sendai, Japan, Jan. 23-24, 2023
26	13th International Workshop on Nanostructures & Nanoelectronics, RIEC, Sendai, Japan, Mar. 7-8, 2023
27	2022 IEEE 11th Global Conference on Consumer Electronics, Organized Session Co-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, 2023

Professors	21
Associate Professors	19
Assistant Professors	16
Specially Appointed Professors	3
Specially Appointed Associate Professors	1
Specially Appointed Assistant Professors	5
Specially Appointed Research Fellows	3
Research Fellows	5
Administrative Staff（Including Limited Regular Employees）	28
Technical Staff（Including Limited Regular Employees）	14
Total	115

2. Researchers (FY2023)

Foreign Researchers	Visiting Professors	1
	Visiting Associate Professors	6
Cooperative Researchers of Private Company etc		15
JSPS Research Fellowship for Young Scientists		8
JSPS Postdoctral Fellowship for Overseas Researchers		2
Invitation Fellowship for Research in Japan		1
Contract Researchers		2
Contract Trainees		1
Total		36

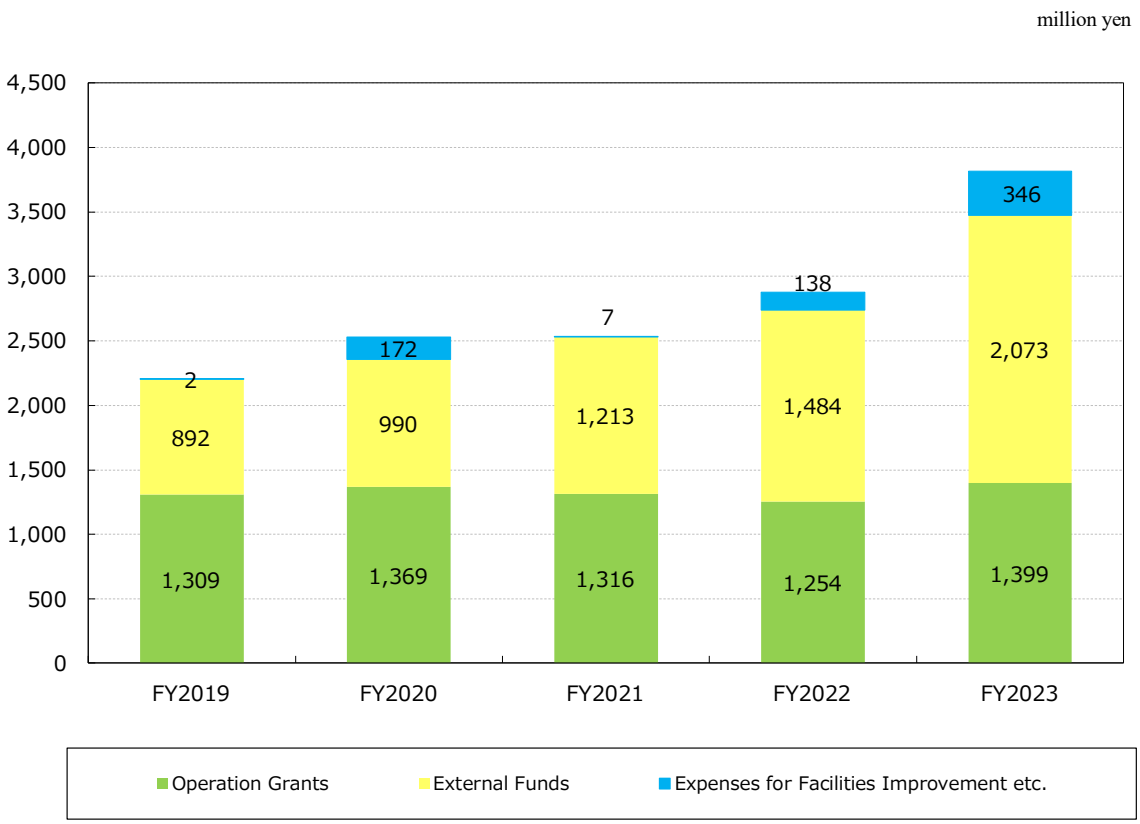
3. Students

as of May 1, 2023

	School of Engineering	Graduate School of Information Science	Graduate School of Biomedical Engineering	RIEC	Total
Undergraduate Students	59 (2)				59 (2)
Master Course Students	89 (3)	47 (9)	4		140 (12)
Doctor Course Students	25 (14)	9 (6)	7		41 (20)
Institute Reserch Students				0	0
Total	173 (9)	56 (15)	11	0	240 (34)

4. Budget

Budget Shift



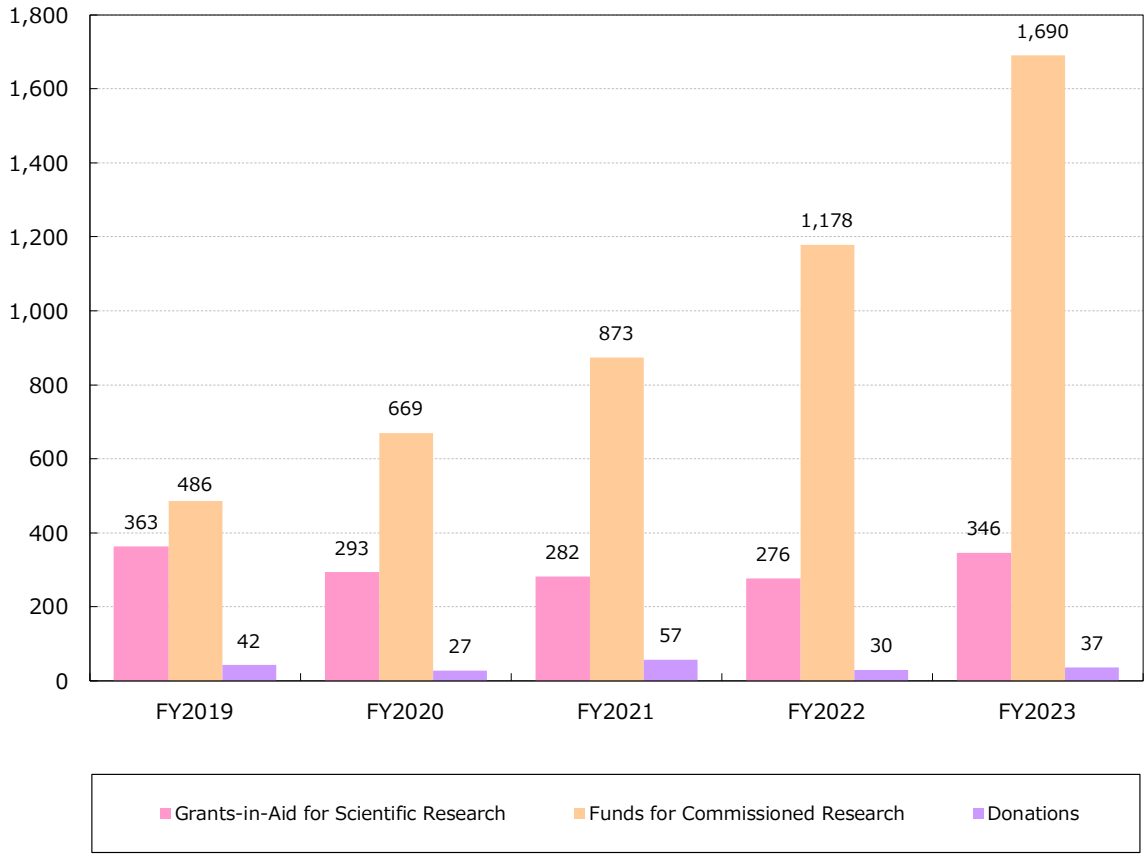
■ Budget Summary

thousand yen

Categories		FY2019	FY2020	FY2021	FY2022	FY2023
Operation Grants	Personnel Expenses	742,128	801, 695	744, 591	699, 851	771, 183
	Non-Personnel Expenses	566,533	567, 249	571, 737	553, 851	628, 159
Operation Grants Total		1,308,661	1,368,944	1,316,328	1,253,702	1,399,342
External Funds	Grants-in-Aid for Scientific Research	363,325	293, 404	282, 400	276, 146	346, 119
	Funds for Commissioned Research	486,053	669, 454	873, 456	1, 178, 325	1, 689, 946
	Donations	42,436	27, 200	57, 422	29, 604	36, 742
	Indirect Expenses	155,852	172, 874	234, 487	315, 346	455, 413
External Funds Total		891,814	990,058	1,213,278	1,484,075	2,072,807
Expenses for Reconstruction		1,936	172, 477	6, 732	20, 472	32, 956
Expenses for Relocation		0	0	0	0	0
Expenses for Facilities Improvement		0	0	0	117, 997	313, 203
Expenses for Facilities Improvement etc. Total		1,936	172,477	6,732	138,469	346,159
Total		2,202,411	2,531,479	2,536,338	2,876,246	3,818,308

External Funds

million yen



■ External Funds

thousand yen

Categories	FY2019	FY2020	FY2021	FY2022	FY2023
Grants-in-Aid for Scientific Research	363,325	293,404	282,400	276,146	346,119
Funds for Commissioned Research	486,053	669,454	873,456	1,178,325	1,689,946
Donations	42,436	27,200	57,422	29,604	36,742
Total	891,814	990,058	1,213,278	1,484,075	2,072,807

Annual Report 2023

Research Institute of Electrical Communication
Tohoku University

2-1-1Katahira, Aobaku, Sendai 980-8577, Japan
Tel. +81-(0)22-217-5422　Fax. +81-(0)22-217-5426
https://www.riec.tohoku.ac.jp/en/

Research Institute of Electrical Communication
Tohoku University

2-1-1 Katahira,Aobaku,Sendai 980-8577, Japan
Tel. +81-(0)22-217-5420 Fax.+81-(0)22-217-5426
https://www.riec.tohoku.ac.jp/en/