Research area in Strategic Objective *“Co-creative research for opening up the quantum frontier"*

Exploring quantum frontiers through quantum-classical interdisciplinary fusion

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Overview

The objective of this research area is to develop a wide range of quantum computers, quantum communications and quantum sensors, either alone or in combination, to explore new quantum frontiers. In pioneering hardware, assembling systems, discovering new applications and developing software, new developments are often opened up through quantum-classical synergies and the fusion of different disciplines such as elementary particles, cosmology, condensed matter physics, chemistry, materials engineering, electrical and electronics, information processing, mechanical engineering, computational science, control theory, AI, and fundamental mathematics. The quantum technologies that have been developed so far do not fully utilize the conventional technologies required to exploit the quantum properties, and current quantum technologies are not yet sufficiently large-scale or superior in practical issues. For this reason, we are actively promoting the integration of quantum with other disciplines and at different levels. To this end, we promote various collaborations and fusions in peripheral devices, electronics, system architecture and algorithms. We also explore quantum science as an extension of fundamental science, such as new quantum systems with high potential, hybrid methods of different quantum systems and quantum control methods, by using atoms, molecules, ions, light, superconducting materials, semiconductor materials, process technology, laser technology, etc.

Exploring these new quantum frontiers will enable us to solve, predict, diagnose and control problems that were previously impossible. It is also expected to contribute not only to future economic development but also to the realization of an advanced safe and secure society.

Research Supervisor’s Policy on Call for Application, Selection, and Management of the Research Area

1. Background

Decades after the beginning of basic research on quantum information, big research institutes and corporations are developing prototype quantum cryptography systems, quantum sensing devices, quantum computers with hundreds of qubits, and quantum annealers with thousands of qubits. Some of them also provide use via the cloud, and now many research institutes and companies in various fields are trying to use them practically. These quantum technologies are the subject of intense research and development competition both domestically and internationally, as revolutionary technologies that will significantly change future society. However, there are still a significant gap in the current state of quantum technology towards its full-scale practical application.

Current quantum computers face many problems, such as the lack of error correction, their applicability to only to specific problems, and the fact that superconducting qubits can only operate in cryogenic environments, so breakthroughs are needed to increase the number of qubits and to achieve high-density wiring. There are several types of practical quantum bits, including superconducting, ionic, optical, atomic and semiconducting, etc., but it is not clear which will be the most promising yet. There are many challenges to the practical application of quantum error correction, which is still in the theoretical stage, such as the lack of direction for a good combination with noise mitigation techniques, early FTQC (Fault-Tolerant Quantum Computation), which are already in use, and future full FTQC. Utilization research is progressing and there are applications in various fields, from logistics to finance, but we believe that further development of as yet undiscovered applications is still to come. AI, for example, is now being studied not only for quantum-assisted AI but also quantum empowerment by AI. AI, for example, is now being studied not only for quantum-assisted AI but also quantum empowerment by AI. Recently, the search for new possibilities is also progressing, such as the momentum of cooperation between elementary particle/cosmology and condensed matter physics.

Quantum communication is also not just a matter of quantum cryptography, and in conjunction with the above-mentioned issue of high-density wiring, large-scale quantum computers via quantum communication is being considered as an urgent matter today. Further ahead will come the era of “quantum computing via the quantum internet” rather than “quantum computing via the current classical cloud.” It will be the era of QTTH (Quantum To The Home) instead of the current FTTH (Fiber To The Home).

Compared to quantum computers, the image of quantum sensors and quantum life forms may not yet be solidified, but they are gradually becoming a reality. If we do not think about it now, we won't develop.

Under these circumstances, in addition to CREST “Quantum Technology” and PRESTO “Quantum Functionalization,” “Quantum Bio,” and “Quantum Software” areas related to quantum, JST's Strategic Basic Research Programs have also been developed many CREST and PRESTO areas such as optics and electronics (“Advanced Photonics” and “Nano-electronics”), materials and devices

("Two-Dimensional Films" and "Topology"), and computers and information processing ("Computing Frontiers"). As with other projects in general, rather than simply to stop when the period comes to an end, it is important to set up a place where the results of these projects will interact with each other and lead to new developments. For this reason, this area will promote collaboration among different quantum layers, and while focusing on fusion with related different fields, we will also explore and develop new quantum frontiers by exploring and fostering sharp elemental technologies.

2. Principle of invitation project and selection

(1) Basic policy and implementation structure

This research area aims to realize future quantum science and technology through the co-creative integration of a wide range of disciplines, including mathematical sciences, information engineering, AI, electrical and electronic engineering, mechanical engineering, materials engineering, chemistry and life sciences. In doing so, it aims for breakthroughs at all layers, including materials, devices, systems and applications. As such, this is a hybrid area where many fields and layers collaborate, and new elemental technologies grow significantly through the interaction between CREST (networked research) and PRESTO (individual research).

A) CREST

we expect co-creative proposals that lead to new quantum frontier areas through collaboration and fusion of different technical fields and disciplines, different methods and technologies, and different layers within quantum science and technology, as this is team-based research.

B) PRESTO

we expect the proposer's own unique and innovative proposals, such as new quantum systems, control systems, and principles, as this is individual research,

(2) Research fields assumed

A) Fusion of AI and quantum technology:

This field is expected to become important in the future, but there have not been many proposals in this project so far. For example, (1) new quantum technology is developed with the help of classical AI (partly overlapping with the following C), (2) "Quantum AI," i.e., AI incorporating quantum technology, is pursued in terms of concept or implementation, (3) other fusion forms, and many others are possible. It can be specific machine learning, not vague AI.

B) Examples of integration of technical fields for systemization and examples of fusion of fundamental sciences:

Fusion of quantum technology and system architecture, compilers, low-temperature CMOS, three-dimensional packaging, microwave control, cooling technology, laser control technology, superconductivity technology, materials and process technology, extreme measurement technology, etc., toward realization of quantum computers, quantum sensors, quantum communication and cryptography, etc.

Fusion of elementary particles/cosmology and condensed matter physics, fusion of life science and quantum computation/quantum measurement, fusion of quantum information processing and classical information processing, fusion of different quantum systems such as atoms, molecules, ions, light, and superconductivity, fusion of macroscopic quantum systems and microscopic quantum systems, etc.

C) Examples of exploring new qubits and control methods:

Discovery and fabrication of novel quantum systems with high potential not found in existing quantum systems. Control methods that significantly improve quantum coherent time. Methods for error correction in quantum computation. Stable control methods for large-scale quantum systems using algorithms such as machine learning, AI. Smooth control methods in quantum/classical hybrid systems, new control methods to connect different qubits, etc.

D) Examples of utilization of quantum science and technology:

Research to exploit maximum potential of quantum computer such as mitigation, error correction and early FTQC, full FTQC, etc. Development of methods of solving VQE (Variational Quantum Eigensolver), QAOA (Quantum Approximate Optimization Algorithm), etc.

E) The above is just a list of specific examples of themes that are open to proposals in this research area, but we will also welcome original proposals based on new ideas regardless of these examples. On the other hand, proposals that merely delve deeper into or implement existing technologies that have been worked on by someone else in a big PJ will not be accepted.

3. Research periods and research funds

The research period for CREST is up to five and a half years from the time the proposal is adopted. The upper limit of the initial research budget per project is 300 million yen (direct costs) when systemization is included in the collaboration and fusion of different technologies and hierarchies, and the upper limit of the initial research budget is 150 million yen (direct costs) when the main focus is on verification of principles for challenging collaboration and fusion. The research period for PRESTO is up to three and a half years from the time the proposal is adopted. The maximum initial research budget is 40 million yen (direct costs) per proposal.

4. Principle of research-area management

This research area is a hybrid of the CREST and PRESTO areas. To promote fusion of different fields within the area, we will support collaboration among PRESTO researchers. Depending on the situation, we will also be able to support collaboration among CREST teams and between PRESTO and CREST researchers. In addition, we will also facilitate the formation of networks for information exchange and collaboration with researchers inside and outside of the research area. At the start of research, site visits to each research proposal are conducted to confirm the research environment and to promote smooth research. Research progress report meetings will be held once a year for CREST and twice a year for PRESTO. A post-project evaluation meeting is held for both CREST and PRESTO in the final year of the project when the project is completed. For CREST, an interim evaluation meeting is held approximately three years after the start of research. In addition, workshops and public symposiums will be held to disseminate the results of the research in the research areas.