Research Topic

(1) Body of the AI-robot Scientists

Progress until the fiscal year 2022

1. Summary

Robotic platforms and micro-robotic tools are being developed to enable accurate, precise, and dexterous manipulation beyond the physical capabilities of human scientists to perform scientific experiments that could not be done by human scientists alone.

2. Progress

Experiments in the field of life sciences require accurate, precise, and complex tasks under a microscope. However, even skilled scientists often encounter failures due to the limitations of human physical abilities. Furthermore, existing robotic technologies excel at routine tasks for handling rigid objects but struggle with non-routine tasks involving small and flexible samples, such as samples taken from plants and animals.

In this project, we are proceeding with development in two steps. First, we aim to surpass the accuracy, precision, and dexterity of skilled scientists in handling samples in life science experiments through remote control of robots or automation. Then, we aim to integrate AI with the robotic system to autonomously perform experiments. Currently, we are working on prototyping platforms and micro-robotic tools in preparation for integration with AI.

(1) Robotic platform (Harada-PI)

As a platform for autonomous scientific exploration, we have developed the AI Robot Platform shown in Fig. 1. This platform consists of four robotic arms with different functionalities placed around the experimental subject under a microscope. The robotic arms can be equipped with various experimental tools, and depending on the requirements of the experiment, AI robotic arms with the required tools can gather and perform the tasks. We have implemented controls to automatically avoid collisions between the robotic arms and collisions between the robotic arms and the surrounding environment to enable tasks within a very small field of view of the microscope. We have successfully demonstrated the platform's tele-manipulation ability to perform highly precise and complex experimental manipulations on a real sample. This remote manipulation will be used to collect learning data for the AI for Skills.

Fig.1 Prototype of the robotic platform
Developed as an open-source platform.
https://aiscienceplatform.github.io/

(2) Micro-robotic tools (Arai-PI)

Micro-robotic tools have been engineered to exceed human physical capabilities, enabling the precise manipulation of small and delicate experimental samples, such as cells. A robotic glass pipette with a force sensor (Resolution: 0.62 μN) has been developed as a micro-robotic tool of AI-robot scientists as shown in Fig.2. The force sensor can detect very small forces that cannot be sensed by the human hand.

Development is also underway for other micro-robotic tools, including a tool that can retrieve individual cells of approximately 10 μm from a plant root (with a diameter of about 100 μm), while simultaneously tracking its position and another tool that collects samples from animal tissues. Such micro-robotic tools facilitate the execution of precision tasks that are challenging for even skilled scientists, due to inherent human physical limitations.

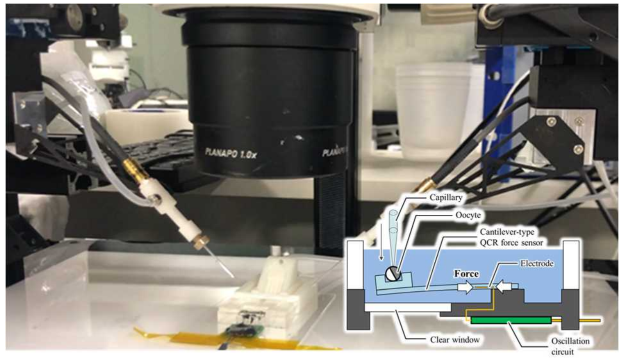

Fig. 2 Micro-robotic tool with a force sensor

3. Future work

After integration of the micro-robotic tools into the robotic platform, AI technologies being developed by the research topic (2) Brain of the AI-robot Scientists will be integrated to step up from the tele-robotic manipulation or robotic automation to autonomous exploration of science. Potential contribution by the AI-robot scientists will be demonstrated by the collaboration with scientists in (3) Scientific applications by demonstrating discoveries that could not be done by human scientists alone.

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Research Topic

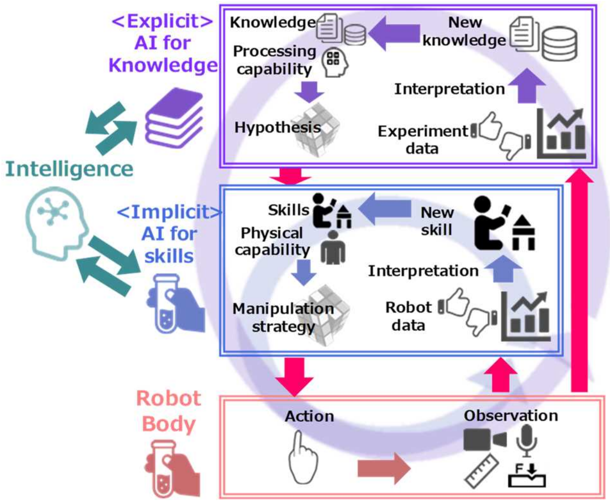
(2) Brain of the AI-robot scientists

Progress until the fiscal year 2022

1. Summary

The brains of AI-robot scientists, which autonomously explore science, require intelligence to plan actions on the target, observe its reaction, and update the plan. If this update can be performed autonomously, then the AI-robot scientists can enhance their intelligence through autonomous interaction with the environment.

In the project, it is assumed that the brains of AI-robot scientists can be developed by integrating (1) **AI for Knowledge**, which handles explicit data to interpret experimental results and propose hypotheses, (2) **AI for Skills**, which handles implicit data to interpret experimental manipulations and propose manipulation strategies, and (3) **Mathematical Foundations**, which abstract knowledge and skills to structure them as intelligence.



2. Progress

Component technologies have been developed for experiments conducted by collaborating scientists.

(1) AI for Knowledge (Takeuchi-PI, Mori-PI)

The AI for Knowledge is under development to **interpret experimental data, acquire new knowledge, and formulate hypotheses, taking into account processing capabilities**. It focuses on explicit knowledge. For instance, an autonomous AI system is currently being developed to generate potential compound hypotheses by utilizing various sources of knowledge, such as compound structures, literature, and previous experimental results. Additionally, an advanced image-processing AI has been designed to automatically analyze experimental data, enabling higher-level interpretation. The automatic quantification of microstructure features in microscopic images enables the acquisition of insights and knowledge that surpass the measurements conducted by scientists.

(2) AI for Skills (Taniguchi-PI, Okada-PI)

The AI for Skills is designed to **learn skills from observed experimental manipulations and formulate manipulation strategies** while considering the robot's own physical capabilities. This methodology specifically focuses on implicit skills. In the future, AI for Skill will have the ability to develop strategies for configuring the physical structure of AI-robot scientists (**Self-Reconfiguration**), allowing for manipulation strategies that are unique to AI robots. As a result, this will enable the realization of experimental manipulations that are distinct from those performed by human scientists.

AI methods are currently being developed to utilize various cues, such as images, sound, and vibrations, in order to learn the interactions between robots and their targets. Through this, the AI can uncover the characteristics of these interactions and form a latent state space. An example of this is the development of robot control based on Multimodal NewtonianVAE (Fig. 1). Additionally, a method has been devised to learn skilled operations through tele-robotic manipulations and autonomously perform tasks using a limited amount of training data.

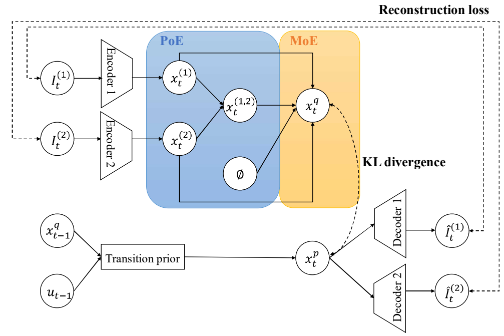


Fig.1 Multimodal NewtonianVAE

(3) Mathematical foundations
(Tanimura-PI, Maruyama-PI, Matsubara-PI)

Scientific exploration is to correlate various data and find a systematic structure in it. The AI for Knowledge and Skills is to search in vast latent spaces, and providing **Mathematical Foundations** to the AI is to correlate the data in the latest spaces to abstract it as intelligence.

The abstract mathematics called category theory is being studied, and conventional neural architectures were successfully expressed using the category theory. Methodologies to incorporate existing principles or discover new principles in the vast latent spaces are also studied.

3. Future work

The AI technologies will be integrated to the robotic bodies for enabling autonomous scientific exploration.

国立研究開発法人 科学技術振興機構 JST Japan Science and Technology Agency

Research Topic

(3) Scientific Applications

Progress until the fiscal year 2022

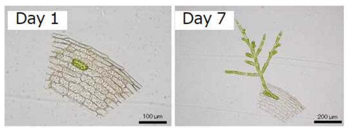
1. Summary

For future social implementation, collaboration with scientists and the application of prototypes of AI-robot scientists are crucial. The project has selected scientific research topics that can greatly benefit from AI and robots.

(1) Bio-stimulants (Uozumi-PI, Arisawa-PI)

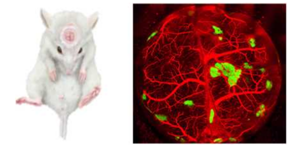
Bio-stimulants, considered as agricultural "medicine" for plants, are anticipated to replace pesticides. AI is utilized to suggest potential organic compound candidates that can serve as effective bio-stimulants. Additionally, experiments are conducted using prototypes of micro-robotic tools to test them, and AI is employed to evaluate the reaction of the stomata to the organic compounds. This method can be widely applicable as a method to measure the electrical characteristics of cells.

(2) Regeneration power of plants (Sato-PI)



Plants possess a remarkable ability for regeneration. By unraveling the mechanisms behind this regenerative capacity, we can make significant contributions toward addressing global food challenges. In this project, AI is used to identify the positions of root cells and track the locations of cells during cell separation. Robots are then employed to collect individual cells one by one. This method has broad applicability, including gene expression analysis of cells in both animals and plants.

(3) Mechanisms of intractable diseases (Takebe-PI)



There are unknown diseases with high fatality rates that pose challenges for modern medicine. However, by harnessing organoids, commonly referred to as mini-organs, we can research these enigmatic conditions. AI is leveraged to detect subtle changes in organoids, and a robot selectively collects cells from regions exhibiting these changes. Furthermore, research focuses on enabling robots to autonomously execute microscopic manipulations, ensuring precise experimentation with limited samples.

2. Progress

As an example, a method has been developed where AI identifies promising compound candidates from literature and compound structure data. A robot performs precise experiments to create and evaluate these candidate compounds, while AI observes the degree of aperture in the microscopic structures called stomata (Fig. 1).

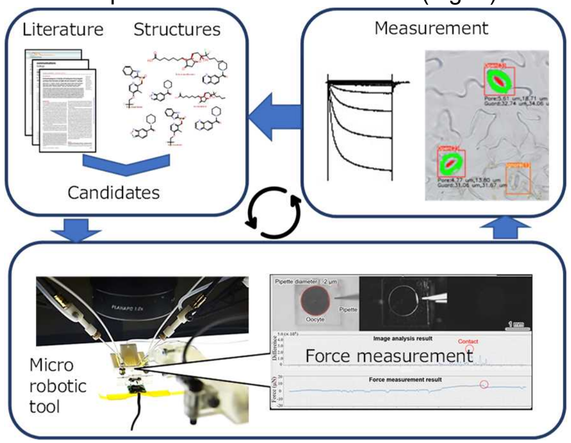


Fig.1 Automated exploration of bio-stimulant candidates

Furthermore, a method has been developed to accurately identify root cells using AI, simulate the position of each cell during separation, and control a micro-robotic tool to collect them (Fig. 2). This enables the correlation of the original cell locations with the analysis of the collected cells.

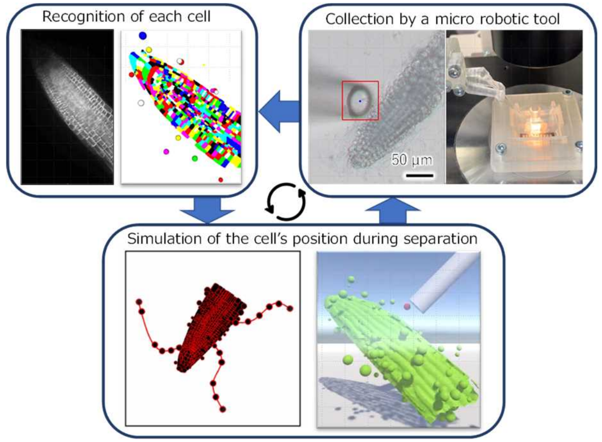


Fig.2 Single-cell collection for gene expression analysis

3. Future work

We have begun applying prototypes of AI-robot technologies using real objects and data encountered in actual scientific exploration. It is essential for future societal implementation to conduct advanced research on AI-robot technologies while understanding the challenges of real scientific exploration. Moving forward, we will continue to apply the progress of research and development in AI-robots to examples of scientific exploration. Our aim is to demonstrate new discoveries achieved by AI-robots conducting experiments that were previously beyond the capabilities of human scientists.