R&D Theme

Body and control system for smart robots

Progress until FY2022

1. Outline of the project

Current robot hardware is extremely hard and heavy because it emphasizes its accuracy and durability (rigidity). Therefore, for example, it is not possible to essentially clear safety issues for supporting people in daily life, such as customer service, housework, welfare, nursing, and medical care. To solve the above problem, by making the robot hardware, including its constituent parts, skin, joints, etc., essentially “soft”, while having the power to support the whole body of a person, we design and manufacture a robot body that has arms, mobile mechanism and hands that can use various tools, with passive flexibility that does not harm humans even if it collides. Specifically, we develop dry/wet hybrid smart robots with self-repairing and maintenance functions by circulating bodily fluids such as oils, coolants and lubricants that can coexist with humans, in addition to flexible joints, flexible skin, magnetic fluid actuators, and high-precision tactile sensors.

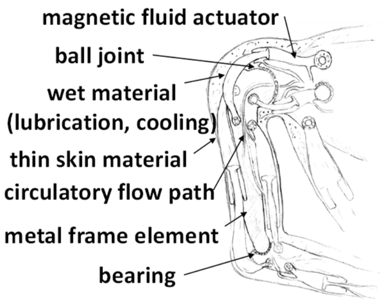


Fig. 1 Wet robot mechanism without gaps

2. Outcome so far

Sub theme 1: Soft robot hardware that can physically support humans with contact

We conducted various experiments on tasks involving physical contact with humans using the world's highest level human-friendly robot (Dry-AIREC). Furthermore, we conducted the following R&D to realize a new dry/wet hybrid smart robot that resembles the human body.

- Based on skeletal recognition by image processing, we conducted simulated motion experiments of functional training related to expanding the range of motion of joints as nursing care/rehabilitation motions performed by contacting the body (Fig. 2).

Fig.2 Extended motion of joint range

-We developed the MRF (Magneto-Rheological Fluid) vane motor that serves as the actuator for the hand, and implemented mechanical design for the hand.

- We established a manufacturing method for self-repairing capsules. Furthermore, we constructed a method for fabricating a channel that allows capsule adsorption, and confirmed that the liquid could be circulated inside the channel using a pump.

- In order to improve the reliability of the stretchable skin sensor, we confirmed the stability of the output against repeated tension by using coiled copper wire and silicon.

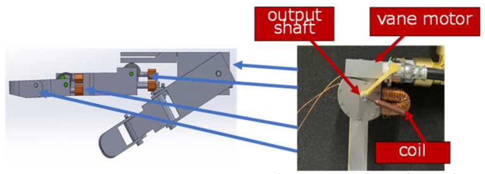


Fig.3 MRF Vane motor driven robot hand

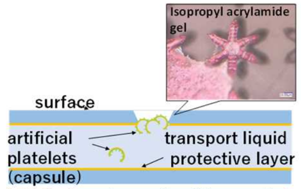


Fig.4 Fabrication of self-repairing capsules

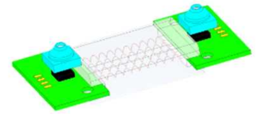


Fig.5 Stretchable skin sensor

Sub theme 2: Robot middleware (OS) for smart robots

By linking OpenRTM and ROS, we realized the operation of Dry-AIREC on the software framework under development. By applying a module that grasps an object by learning using the manipulator's hand coordinates to Dry-AIREC, we confirmed that the same learning model can be used even if the robot is changed.

Sub theme 3: Development of a compiler-coordinated low-power-consumption AI processor that realizes the brains of smart robots

We designed the basic configuration of a low-power AI accelerator processor chip to be installed in a smart robot, and built a design verification and preliminary evaluation environment on FPGA. In addition, we created design information for the next year's chip manufacturing from the basic configuration design.

3. Future plans

We will conduct AI implementation in Dry-AIREC assuming various application scenes involving contact with people, mainly in the nursing care field, and experiments on fluid-driven upper body and hand handling of heavy objects, and fabricate a flow path that allows the adsorption of capsules in the self-repairing function. In addition, we plan to integrate the development of robot hardware, middleware, and AI chips, such as the introduction of compiler-coordinated low-power AI processors into Dry-AIREC.

R&D Theme

AI systems for smart robots

Progress until FY2022

1. Outline of the project

Moravec's paradox is a contradiction that tasks that are easy for humans are difficult for artificial intelligence and robots. In recent years, deep learning technology has advanced rapidly, and AI and robots have been able to perform tasks such as walking, running, visual and auditory recognition, and language-based communication. However, it is still a difficult challenge for even the latest technology to perform a variety of real-world tasks using common hands and tactile sensations.

This study aims to realize robot intelligence that supports human manual labor, especially housework, by utilizing a unique approach called "deep prediction learning" based on the knowledge of neuroscience. Deep prediction learning is a framework that applies deep learning technology to predict high-dimensional changes in sensation and motion in real-time and minimize prediction error. This method has already been used to handle clothes and food and move around the house. We plan to expand the research results in the future.

2. Outcome so far

We conducted several motion learning studies using the human-collaborative robot Dry-AIREC developed in our project, as well as other robots. Here are some examples:

1)Handling various objects with a multi-fingered hand: Object picking is fundamental for many robots. However, most research in this area is limited to grasping planning using visual information. In this study, we proposed a challenging task of grasping diverse objects using the coordinated motion of four fingers with 384 tactile sensors. We achieved this through deep predictive learning and presented our findings at IEEE RA-Letter and ICRA2022 as shown in Figure 1.

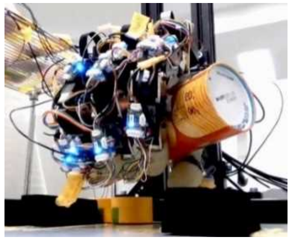


Figure 1: Learning grasping motions of diverse objects through coordinated multi-finger actions.

2)Laundry Task: As part of household operations performed by Dry-AIREC, we collaborated with the Technical University of Munich to conduct laundry handling using deep predictive learning and attention mechanisms (Figure 2, left). The learning of this task was facilitated using a bilateral teleoperation device. We showcased these research findings at IEEE/RSJ IROS2022 (Figure 2, right).

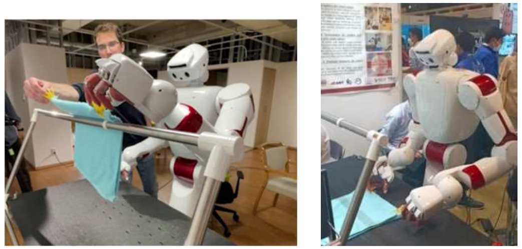


Figure 2: Laundry assistance actions by Dry-AIREC.

3)Language-Motion Learning: We conducted research with the aim of integrating large language models such as ChatGPT with motion. Specifically, we developed a transformative learning model incorporating vector representations from language learning into deep predictive learning models. We presented these results at IEEE RA-L and IROS2022 and were awarded the SIYA-IROS2022.

4)Utilization of Virtual Spaces (Forcemap): In simulated environments, it is possible to obtain information that is not visually perceivable. Taking advantage of this characteristic, we constructed a model capable of predicting force distribution for manipulating multiple objects (accepted for IROS2023). Figure 3 represents the visualization of contact force distribution obtained from multiple object images.

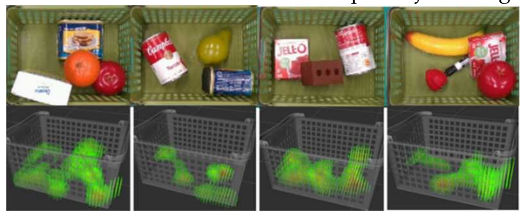


Figure 3: Visualization of Contact Between Objects

5)Model extension based on the Free Energy Principle: We built a variation of the Bayesian recurrent neural network (PV-RNN) grounded in the theoretical framework of the free energy principle. By utilizing real robot data, we are currently advancing the updates to the existing deep predictive learning models.

3. Future plans

In the fiscal year 2023, we plan to release the open-source software EIPL (Embodied Intelligence with Deep Predictive Learning) for deep predictive learning. We will also expand the number of AIREC to enable the realization of a wider range of tasks. We will also develop real-world applications of Forcemap and extend the models through the PV-RNN framework. Furthermore, we are set to commence full-scale collaborative research with the Alan Turing Institute, UK, with whom we signed a memorandum of understanding in 2022, in partnership with Waseda University.

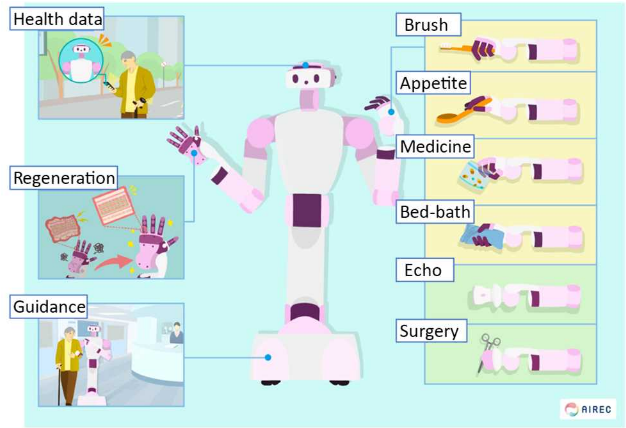
R&D Theme

Technologies for welfare and medical care with smart robots

Progress until FY2022

1. Outline of the project

Research and development have been conducted to develop a smart robot (AIREC, AI-driven Robot for Embrace and Care) to assist healthcare workers and visitors in healthcare facilities and hospitals where elderly care, nursing, and medical care are provided. As AIRECs interact with people, it is necessary for AIRECs to move gently and safely and to be able to use a variety of specialized tools for treatment. AIRECs are expected to play an active role in the medical and welfare fields, taking into consideration their affinity with people and safety.



2. Outcome so far

1) Information infrastructure system for health monitoring

A sophisticated server that stores data in a format that is highly compatible with other databases has been built to enable AIREC to touch people in their daily lives and acquire biometric information for health management. Demonstration experiments for data collection have been initiated at nursing care facilities.

2) Developing robotic hand skin

Our goal is to create a bio-hybrid robotic skin that can replace human hand skin. Focusing on the characteristics of hydrogen-bonding materials, we developed gels with elasticity, adhesive strength, high extensibility, and self-healing properties suitable for human contact (Fig. 1 left).

3) AIREC functions for facility guidance

Thirty-five demonstrations were conducted in hospitals where prototype robots guided visitors to various examination rooms, identifying the functions required for AIREC to "gently" guide people and the challenges to be overcome.

4) Ability to administer and manage medications correctly

We surveyed the needs of nurses and caregivers in current nursing and medical care settings and developed a prototype of the system.

5) Robot hands that can be used in various places

A special hand was attached to the AIREC to simulate the function of providing oral care (Fig. 1 middle). To develop a hand that can perform medical examinations (palpation and care), we constructed an AI that can determine features essential for determining the severity of an affected area (Fig. 1, right) and verified the principle of a tactile sensor.

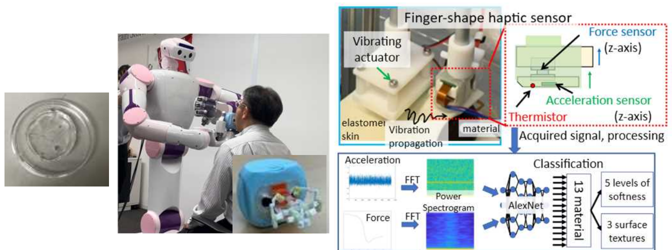


Fig.1 (Left)Hydrogel developed, (Middle)Oral care hand and testing, (Right) Palpation AI.

6) Welfare and medical robot design, quality assurance, international standardization, and risk management

A new standard framework is needed for robots that handle medical devices, therefore a preparatory committee for guidelines was formed. A multi-person location detection system was installed in a nursing facility to enable ongoing data collection and analysis for risk management, safety, and quality assurance. AIREC was installed at the facility to implement and evaluate some of the gymnastics support and conversation functions (Fig. 2 left). A study was conducted to assess the physical characteristics of the elderly (Fig. 2 right).

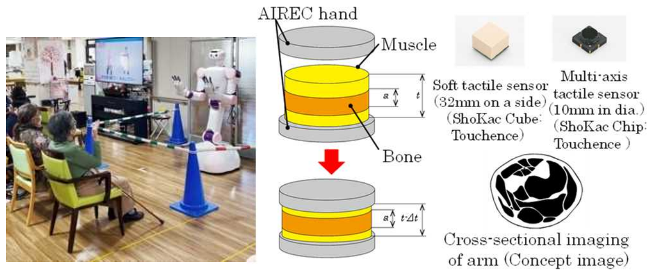


Fig. 2 (Left) AIREC in a nursing facility, (Right) Stiffness measurement method for evaluating arm condition with AIREC hand.

3. Future plans

In the future, we plan to link AIREC with the development results we have achieved so far and introduce AI to enable AIREC to perform each function accurately and autonomously. We also promote research that considers social ethics to enable AIREC to work in society.