R&D Theme

Robot Hardware for Earthwork Innovation

Progress until FY2022

1. Outline of the project

This project aims to achieve "infrastructure construction adapted to diverse environments through collaborative AI robots." A system that can operate in dynamically changing environments, such as natural disaster sites, is necessary to achieve this goal. However, the conventional design philosophy of machine engineering has been limited to pre-determined environments (Figure 2, left). Therefore, we propose the design methodology called "open design" (Figure 2, right) to realize a robust robotic system. In this R&D theme, we have set sub-tasks such as innovative earthwork technologies, innovative robotic mobility technologies, robot platform development, technologies for dealing with river channel blockages, and construction technologies for lunar landing sites. The following section describes the main achievements of this research and development in 2022.
In addition, developed technologies can be applicable to the earth such as natural disasters and etc.

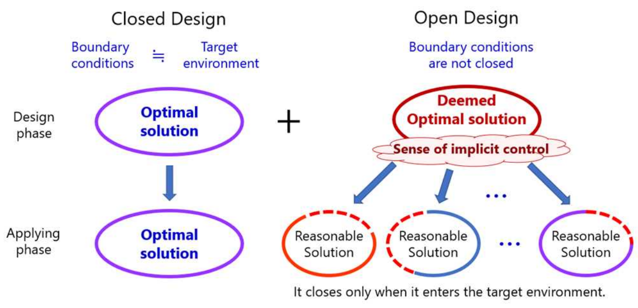

Fig.2 Closed design and open design.

2. Outcome so far

A drainage hose laying robot, which allows for remote installation of drainage hoses during disasters such as river channel blockages, was developed by a group from Osaka University. River channel blockage refers to the phenomenon where landslides caused by earthquakes or heavy rainfall occur, obstructing the flow of the river and forming a natural dam. As the water supply to the river continues, it is necessary to move the accumulated water from the upstream area to the downstream area to prevent debris flows resulting from the collapse of the dam. Currently, drainage pumps are used during the construction of waterways until completion, but their installation is manually carried out in unstable and hazardous environments. To address this problem, we have developed the "i-Centipot Hose," which allows for the remote installation of drainage hoses in unstable environments.

Fig.3 Drainage pump laying robot "i-CentiPot-Hose."

The robot primarily uses a tracked robot for transporting the drainage pump and hose. A feature of the robot is that multiple small robots are placed in between to support the hose to reduce the friction between it and the ground when dragging it. The robot was demonstrated at the international conference IROS 2022 exhibition booth, where concept validation was conducted. Furthermore, we have improved the robot platform for constructing lunar landing sites. In the low-gravity environment of the moon, the compaction efficiency using the weight of rollers, which is effective on Earth, is expected to decrease. Therefore, as shown in Figure 4, we have developed a mechanism that integrates compaction rollers directly beneath the small robot platform. The hardware allows the vehicle's weight to be utilized for compaction and enables control of the compaction force. With this innovation, we anticipate achieving effective compaction even in a low-gravity environment.

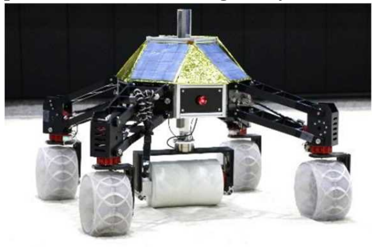

Fig.4 Lunar robot platform with a pressure roller.

Because of the space limitation, only a small part of this year's achievements can be mentioned here. In addition to the mentioned projects, we have also conducted development on various other fronts. These include the "Flexible Dual-Hull Tracks with Adjustable Shape," the "3-ton Electric Tool-Exchange Robot with Precise Arm Control," the "3-ton Mini Hydraulic Excavator Capable of Installing Drainage Pumps," and "Remote Installation Sensing Equipment for Hydrological Observation." These sub-themes demonstrate our commitment to advancing technology and addressing diverse challenges.

3. Future plans

The goal for the research project is to achieve earthwork tasks in dynamic environments using multiple small robots. To achieve this, we will develop several prototypes by 2023 and conduct performance evaluation tests. We believe that these prototype robots will adapt to rapidly changing conditions and enable the completion of earthwork tasks.

R&D Theme

Dynamic Collaboration System for Multiple Robots

Progress until FY2022

1. Outline of the project

To achieve "infrastructure construction adapted to diverse environments," it is crucial to adapt to changing surroundings dynamically. It is effective to incorporate collaboration among multiple robots and enable them to adjust their team composition to address unforeseen circumstances dynamically. However, until now, the architecture and algorithms required for such robots did not exist. Therefore, in this R&D project, titled "Dynamic Collaboration System for Multiple Robots," we aim to establish "Dynamic Collaboration System" that enables the reconfiguration of robot teams. Our initial focus will be on achieving a task involving the transportation of sediment, which is applicable to river channel blockage disasters. We strive to realize a dynamic collaboration AI that adaptively reconfigures the team composition in response to changing environmental conditions (refer to Figure 6). Furthermore, we will conduct verification of the dynamic collaboration AI using multiple construction robots in the 3-ton class.

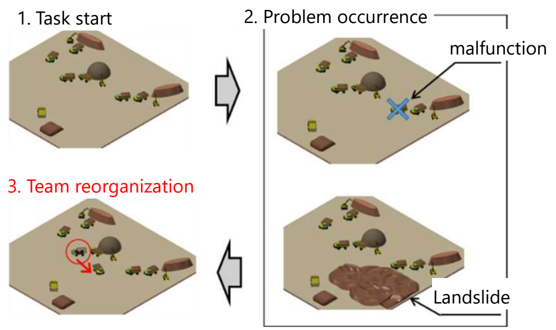

Fig.5 Team reconfiguration in dynamic environments.

2. Outcome so far

We have developed a "Self-Organization" algorithm that enables flexible team composition based on the current site conditions. Specifically, for the task of sediment transportation using excavators and dump trucks, as mentioned earlier, we have constructed an algorithm that reconfigures the team based on parameters such as the amount of sediment, the location of sediment piles and disposal sites, robot performance, and delivery deadlines. This algorithm utilizes the predicted performance (transportable sediment volume) and actual performance (sediment volume transported) to determine the team composition. To validate the above algorithm, we have developed a three-dimensional geotechnical simulator for multiple construction robots using the Vortex Studio simulator. Based on the Self-Organization algorithm, we implemented a motion simulation to achieve excavation and loading of sediment by the excavator and transportation by the dump truck (refer to Figure 6). As a result, we confirmed that this algorithm operates effectively, even in cases where the dump truck experiences a malfunction, by successfully demonstrating the reconfiguration of the team based on the site conditions.

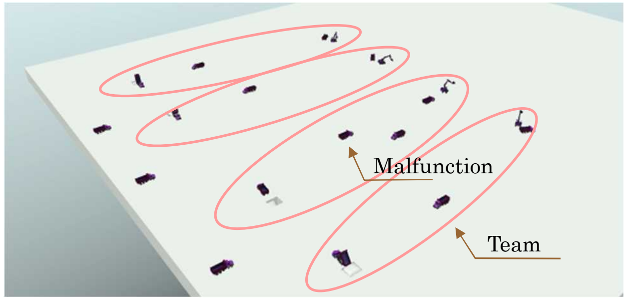

Fig.6 Multi-robots simulation based on self-organization.

Furthermore, to validate the algorithm on real machines, we have developed a simultaneous localization and mapping (SLAM) technique for small construction robots using multiple sensor pods. This position estimation technology for construction robots has several advantages. It can be used in environments where GNSS is unavailable and provides a real-time understanding of the surrounding environment. Additionally, we achieved the execution of sediment transportation tasks by multiple construction robots with the aid of this position estimation technology (refer to Figure 7).

Fig.7 Multi-robots for earth moving operations.

3. Future plans

This R&D project for 2025 aims to achieve the reconfiguration of teams by multiple small construction robots, enabling them to adapt to changing circumstances and successfully perform tasks. To accomplish this goal, we will continue advancing research and development on the "Self-Organization algorithm" until 2023. By the summer of 2023, we aim to demonstrate sediment transportation tasks by six operational construction robots equipped with the Self-Organization algorithm.

R&D Theme

Sensor pod system to Obtain Environmental Information

Progress until FY2022

1. Outline of the project

To achieve "infrastructure construction adapted to diverse environments by multi-construction robots," it is crucial to acquire environmental information and perform evaluations and predictions of the environment. However, technologies for remotely acquiring real-time information in evolving environments and predicting future environmental changes have not been realized thus far. Therefore, in this R&D theme, our primary goal is to develop technologies for acquiring various environmental information, including soil information and the situational status of each robot. We aim to achieve this by deploying a stationary sensor system called the "Sensor Pod" within the environment. Furthermore, we will build a system that aggregates and provides the acquired information to each robot. Additionally, we will develop an "Environmental Evaluation AI" that analyzes this information to predict future ground movements in scenarios such as river channel blockages and landslides.
In addition, developed technologies can be applicable to the earth such as natural disasters and etc.

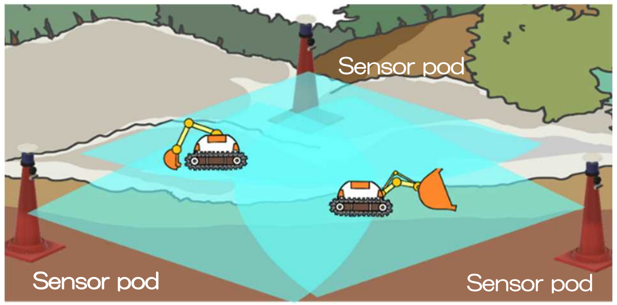

Fig.8 Acquisition of various environmental information by installed sensor pods.

2. Outcome so far

In 2022, as part of developing technologies for the stationary sensor system called the "Sensor Pod," field experiments were conducted by Kyushu University to validate a method for estimating ground strength using deviations in vibration waveforms, which was developed in 2021. The results of this experiment showed that the proposed method significantly measured an indicator that converges with an increase in the strength of the ground, compared to the conventional method that used vibration sensors attached to a vibratory roller.
Furthermore, we conducted development and operational verification experiments for a technology that utilizes multiple LiDAR-equipped Sensor Pods to estimate the real-time positions of multiple construction robots. The results of the experiments confirmed that it is possible to track the real-time positions of multiple construction robots. (Please refer to Figure 9.)

Fig.9 Multiple sensor-pods to estimate the location of multiple construction robots.

Meanwhile, the Nara Institute of Science and Technology has been developing a technology that estimates the moisture content within the soil by utilizing temperature changes on the ground surface. They have successfully developed a moisture estimation technique that can adapt to unstable sunlight conditions, such as cloudy weather.
Additionally, research and development efforts have been devoted to assessing the environment using the environmental data obtained from the Sensor Pods. One of these efforts focuses on estimating the condition of dams using displacement data obtained from the Sensor Pods during river channel blockage. In 2022, we developed the "virtual site model" of river channel blockages that we constructed using the finite difference method. With this model, we developed forward analysis PINN (Physics Informed Neural Network) for deformation analysis considering groundwater level fluctuations and collapse risk analysis, followed by PINN for continuum elastic analysis this year.
The second development is Environmental Evaluation AI, which assesses disasters based on image data from disaster environments. In this study, we have developed a V&L (Vision and Language) model capable of using figurative expressions in image descriptions and a method for evaluating its performance. Currently, we are verifying the validity of this AI framework by applying it to past disasters and constructing an image-language dataset specifically for landslide collapse sites. Furthermore, we are working on integrating the framework with a Large Language Model (LLM) and advancing rule-based language generation.

3. Future plans

This R&D project for 2025 aims to utilize the Sensor Pods to obtain information from disaster environments, perform environmental assessments, and provide information to collaborative AI robots. To achieve this, by 2023, we will integrate various sensing technologies developed throughout the R&D process into the Sensor Pod. Additionally, we will continue to realize a prototype of the Environmental Evaluation AI for conducting environmental assessments and future predictions.

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