R&D Item

5． System integration for emergency surveys of river channel blockages

Progress until FY2024

1. Outline of the project

This project aims to enable infrastructure construction in diverse environments using a collaborative AI robot system, with a focus on applications at natural disaster sites involving river channel blockages. To this end, we are advancing R&D in three areas: (1) System integration for emergency surveys of river channel blockages, (2) System integration for emergency restoration work of river channel blockages, and (3) Technologies for responding to river blockages. In (1), Rapid situational assessment is crucial for emergency surveys, requiring not only image data but also water levels, terrain, and ground strength. Since these sites are often in mountainous areas, manual data collection is difficult. We are therefore developing remote data collection technologies—centered on drones—and an integrated system to aggregate this data. Figure 3 provides an overview of the technologies and system, followed by a summary of key outcomes from the 2024 efforts in emergency survey system integration.

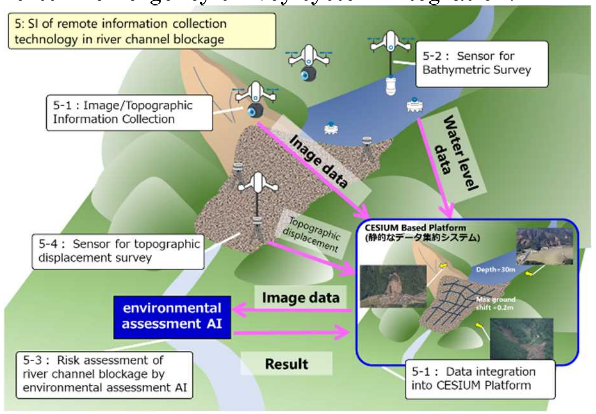

Figure 3: Emergency Survey Technologies.

2. Outcome so far

In fiscal year 2024, this research project developed an integrated emergency survey system for disaster response scenario in Figure 1. We also conducted field tests to acquire data in a real environment. The system consists of multiple components: (1) Aerial imagery and 3D terrain mapping using drones, (2) Remote deployment of water depth sensors in flooded areas via drone, (3) Remote deployment of sensors for detecting terrain displacement, and (4) Risk assessment of river blockage collapse areas. The collected data and assessment results are integrated into an information-sharing platform built on Cesium (The Platform for 3D Geospatial, by Cesium GS, Inc.). To validate the system, field experiments were conducted in October 2024 at the Imokawa River in the Chuetsu region. These included drone-based aerial surveys, sensor deployment, and data acquisition. Notably, the water level sensor was transported over 400 meters by drone, autonomously deployed in water, anchored in place, and used to transmit data—achieving Technical Readiness Level 5 (TRL5), indicating proven functionality in a simulated environment (see Figure 4). The collected data were then visualized using the platform. Figure 5 shows an example of time-series data from the water level sensor overlaid on the 3D terrain model of the Imokawa site.

Figure 4: Drone takeoff/landing site (left), the drone carrying the sensor device (center), the device just before water landing during autonomous transport (right).

Figure 5: The Information-Sharing Platform

We also developed a system that analyzes aerial imagery captured by drones and uses AI to assess the collapse risk of targeted river blockage sites. The system qualitatively estimates the likelihood and type of potential secondary disasters, and is integrated into the information-sharing platform. In general, AI-based systems require large volumes of training data. However, for slope failure analysis—the focus of this project—the task requires expert knowledge, and suitable datasets are limited. To address this, we created a new dataset specifically designed for learning about slope failure risks, and developed a novel AI system capable of efficiently learning from limited data and incorporating expert knowledge to assess collapse risk. The system demonstrated superior performance in identifying disaster types, causes, and potential future risks compared to conventional methods.

3. Future plans

The intermediate target for 2025 is to demonstrate this capability in a simulated natural disaster environment.

To achieve this, we plan to complete system integration by 2025 and conduct a demonstration in the simulated river channel blockage environment at Kyushu Univ. in the summer, and achieve Technical Readiness Level 5.

R&D Item

6. System integration for emergency restoration work of river channel blockages

Progress until FY2024

1. Outline of the project

This project aims to enable infrastructure construction in diverse environments using a collaborative AI robot system, with a focus on applications at natural disaster sites involving river channel blockages. To this end, we are advancing R&D in three areas: (1) System integration for emergency surveys of river channel blockages, (2) System integration for emergency restoration work of river channel blockages, and (3) Technologies for responding to river channel blockages. The second area—emergency restoration—requires work using construction machinery. However, since river channel blockages typically occur in mountainous regions, transporting large equipment is challenging. To address this, we aim to develop an emergency restoration system centered on the deployment of drainage pumps, using multiple compact construction robots (weighing less than 3 tons) that can be transported by helicopter. Figure 6 shows an overview of the system integration for emergency restoration. Below, we present the main outcomes of the 2024 efforts in the system integration of emergency restoration for river channel blockages.

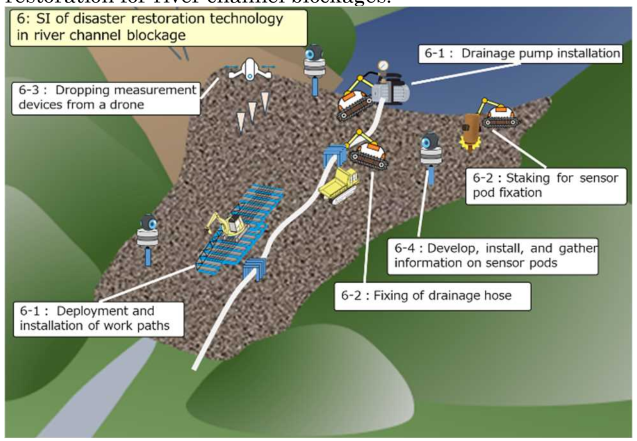

Figure 6: SI for emergency restoration work

2. Outcome so far

In this R&D Item, we have been working on building an emergency restoration system by integrating technologies corresponding to the "Preparation for Emergency Restoration Work" and "Emergency Response" phases of the river channel blockage disaster response scenario shown in Figure 1. In river channel blockage disasters, there is a risk that natural dams formed by collapsed slopes may fail due to river overflow, potentially triggering large-scale debris flows. To prevent such secondary disasters, urgent countermeasures are required to redirect upstream water downstream. Therefore, in 2024, we focused on developing a system for deploying drainage pumps to transfer water from the upstream impounded area to the downstream. Since river blockages often occur in mountainous regions, transporting construction equipment is challenging due to the weight limits of helicopters. To address this, we developed a multi-robot system composed of compact construction robots that can be transported by helicopter without disassembly. This system enables emergency restoration work to be carried out by a small number of supervisors, without the need for on-site workers. Given the possibility of both gradual and sudden environmental changes during restoration in such settings, real-time monitoring is essential. To support this, we developed a stake-type sensor pods for collecting environmental data. These pods are installed using remotely operated construction robots capable of performing fine manipulation tasks. Figure 7 shows the insertion of a stake-type sensor pod into the ground using a construction robot in a simulated environment at Yanmar's test site, as well as image data collected from the sensor installed in the Kyushu University field environment.

Figure 7: Installation of the stake-type sensor pod (left) and collected environmental data (right).

Next, we introduce the system for deploying drainage pumps. Compact construction machines, which can be transported without disassembly, allow for rapid response. However, during the process of submerging drainage pumps, there may be cases where the machine's arm is not long enough to reach from the pond side. To address this, we developed a pump deployment system using a lightweight frame. Figure 8 illustrates the operation of the tool: by connecting two extension frames to the main frame holding the submersible pump, the left side is pushed forward, allowing the pump on the right side to be placed into the water. This system was tested via remote operation at a simulated river channel blockage embankment field owned by Kumagai Gumi's research institute. Additionally, a crawler carrier dump truck was used to transport these tools, with some sections of travel conducted autonomously.

Figure 8: Operational Test of Pump Deployment

3. Future plans

The goal of this project for 2030 is to enable infrastructure construction in diverse environments, including those affected by natural disasters. The target for the end of 2025 is to demonstrate this capability in a simulated natural disaster environment. To achieve this, we plan to complete system integration by 2025 and conduct a disaster response demonstration in a simulated river blockage environment to be constructed at Kyushu University during the summer. Through this demonstration, we aim to achieve Technical Readiness Level 5 (TRL5), indicating that the core functions and performance of the emergency restoration system have been validated under simulated conditions.

R&D Item

7． Technologies for responding to river channel blockages

Progress until FY2024

1. Outline of the project

This project aims to enable infrastructure construction in diverse environments using a collaborative AI robot system, with a focus on applications at natural disaster sites involving river channel blockages. To this end, we are advancing R&D in three areas: (1) System integration for emergency surveys of river channel blockages, (2) System integration for emergency restoration work of river channel blockages, and (3) Technologies for responding to river channel blockages. The system integration for emergency surveys and emergency restoration work aims to facilitate the early social implementation of disaster response technologies. At the same time, foundational research is also essential to ensure that these systems can adapt to diverse environments. With this in mind, our project is conducting R&D focused on proof-of-concept for next-generation robotic systems, particularly designed for addressing river channel blockages.

2. Outcome so far

This research and development initiative focuses on robotic technologies that can flexibly respond to various scenarios, with the goal of enabling effective recovery operations for river channel blockages. Below, we introduce the main achievements from fiscal year 2024.

For the installation of drainage pumps—a key part of the system integration for emergency river channel blockage—Kumagai Gumi has proposed a system using compact construction equipment, as shown in Figure 8. However, this approach may not be feasible in areas with unstable ground conditions. In response, a research group at Osaka Institute of Technology has developed a modular transport container system called “BRAINS.” This system allows the working unit and the mobile unit to be separated and reconnected as needed, making it easier to adapt to changing conditions at disaster sites. The container is divided into two levels: the upper level houses the working unit, while the lower level contains the mobile unit. By swapping out mobile units according to the site environment and recombining them with the working unit, a wide range of construction robot configurations can be realized. In 2024, the team successfully created a scale model of this concept and conducted functional tests in an indoor environment. Figure 9 shows an overview of the BRAINS container enabling the separation and recombination of the mobile and working units (top left), the d-FlexCraw mobile unit designed for rough terrain (top right), and the i-CentiPot Ammonite working unit used for hose deployment (bottom). In this figure, the hose-deploying working unit is mounted on a standard crawler-type mobile platform.

Figure 9: An overview of the modular transport container "BRAINS" that enables separation and recombination (top left), a mobile unit to traverse challenging terrain (top right), and the working unit designed for hose deployment (bottom).

Meanwhile, for excavation work in earthmoving during the construction of temporary drainage channels, hydraulic excavators are currently used. To replace the excavators, we are conducting R&D on new excavation methods that would allow this task to be performed by multiple small construction robots. Specifically, we aim to establish an excavation technique using two compact robots, by dividing the excavation process into two functions: loosening and scooping. In 2024, we successfully automated each step of this process: one compact construction robot used a chiller (a ground-loosening tool, shown in the top left of Figure 10) to loosen the soil (top right), while a separate skid loader collected the loosened soil.

Figure 10: Loosening of the ground using a chiller and soil collection by compact construction robots

In addition to this, we also advanced research on dynamic cooperative control technologies for multiple construction robots working together to respond to river channel blockages. Furthermore, we developed AI-based learning methods for excavation strategies that can adapt to varying ground strengths.

3. Future plans

The goal of this project by 2030 is to enable infrastructure construction in diverse environments, including those affected by natural disasters. To achieve this, the current R&D theme focuses on foundational research that supports adaptability to a wide range of environmental conditions. By the end of the project in 2025, we aim to verify the effectiveness of each technology and reach Technical Readiness Level 4 (TRL4), where the basic functions and performance of the technologies and systems are demonstrated in a controlled environment.