System Integration of Construction Planning and Robots for a Joint Civil Engineering and Robotics Course

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Abstract -

This study describes the development of a system that links construction planning and construction robots for civil engineering and robotics-integrated education programs. In this program, it is possible to learn construction planning and automation using model construction robots. The major issue was that the information in the developed construction plans could not be used directly for the operation of the model construction robots. Therefore, to create innovations or ideas in an environment closer to future automated construction sites, where information, communication, and robot technologies are linked, a web application for construction planning was built and linked to model construction robots via API. Although some issues were revealed in the demonstration, the system worked as intended.

Keywords -

Education; Construction planning; Construction robots; Automation; Web applications; API; System integration

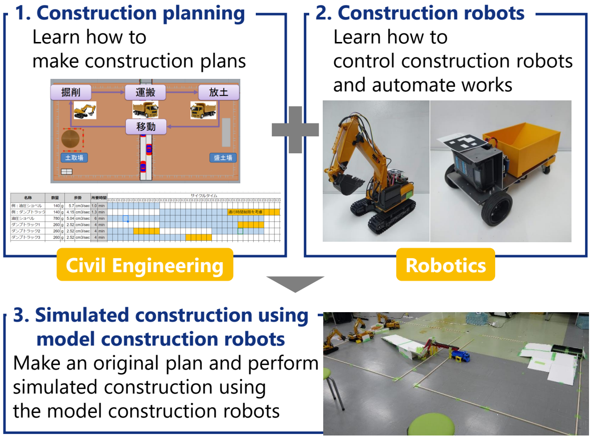

Figure 1. Basic configuration of the education program

1 Introduction

Low productivity and labor shortages are major issues in Japan's construction industry. To solve these issues, the Ministry of Land, Infrastructure, Transport, and Tourism has set a policy called "i-Construction" and aims to improve productivity in the construction industry by 20% by 2025 [1]. One of the key points of "i-Construction" is to fully automate the construction site and transform it into a state-of-the-art factory. Furthermore, open innovation is emphasized to introduce new information, communication, and robot technologies into construction sites [2]. This trend has become important not only in Japan but also in all over the world [3]. Therefore, it is necessary to educate civil, ICT (Information and Communication Technology), and robotics engineers to collaborate across disciplines.

Our laboratory on Construction System Management for Innovation [4] has been advancing research and development and education to contribute to "i-Construction." One educational activity is the development of a civil engineering and robotics integrated education program [5]. The purpose of this educational program is to create innovations to improve productivity in earthworks and to develop human resources. In this program, it is possible to learn construction planning and automation using model construction robots. Participants can experience the process of creating innovation through a simulated automated construction that combines construction planning and model construction robots. In the field of civil engineering, there are programs to study BIM (Building Information Modeling) and ICT Construction as educational programs [6, 7]. There are also educational programs that introduce unmanned aerial vehicles [8] and develop IoT applications [9]. On the other hand, in the field of robotics, educational programs and competitions to create ideas and develop robots are widely conducted. The topics vary from game-like challenges to realistic problems [10, 11, 12]. The novelty of our educational program is that it focuses on the automation of earthworks, and integrates the knowledge of civil engineering, such as construction planning, and robotics, such as autonomous control.

This educational program has been conducted as a four-day intensive course for graduate students every year since 2021, with continuous improvements. In 2021, a basic configuration was built, and it was confirmed that the participants created various ideas through practice. However, the only model construction robot that could be used in this educational program was an excavator. In 2022, although an environment that could handle full automation at construction sites was prepared by robotizing all excavators and dump trucks, some issues were revealed. The major issue was that the information in the developed construction plans could not be used directly for the operation of the model construction robots. When the construction plan was changed, it was necessary to modify the programs following the plan directly and certainly by hand. In other words, hard coding was required. This issue may occur not only in this educational program, but also in actual automated construction. In the research and development of the overall system of automated construction machines, higher-level systems have been built to connect the construction plan or tasks with low-level controllers of construction machines [13, 14, 15, 16]. Therefore, such kind of integration will be essential for future automated construction.

To address this issue, a system linking construction planning and construction robots was developed and introduced into our educational program. This changes the educational program to one that allows participants to experience the process of creating innovations in an environment that is more similar to a future construction site where information, communication, and robot technologies are linked. This paper describes the revealed issue, the developed linking system between construction planning and model construction robots, and a demonstration of the system through the practice of an educational program in 2023.

2 Basic Configuration of the Education Program

The basic configuration and features of our education program are explained (Figure 1). As mentioned above, this education program aims to create innovation to improve productivity in earthworks and develop human resources. This process was divided into the following three parts:

1. **Construction planning**

   The method to build construction plans under site conditions and constraints is taught as a content of civil engineering course. Specifically, the layout of the construction equipment is planned, productivity is measured, the cycle time is calculated, and is examined to ensure the plan satisfies the required construction period for a simulated earthwork. Moreover, the direct construction cost for the built plan is calculated. This plan is built on an Excel sheet and a PowerPoint file prepared as teaching tools.

2. **Construction robots**

   The method to control construction robots and to automate construction works is taught as a content of robotics. Specifically, programs to control the angle of joints and the position or velocity of the body of the small model construction robots prepared as teaching tools are developed. The system of the robots is based on ROS (Robot Operating System) [17] and the programming language is Python.

3. **Construction planning and simulated construction using model construction robots**

   In the simulated construction, it is required to transport iron beads instead of soil in a specified weight within a required construction period in the field of 2 m in length and 4 m in width. Two excavators, three dump trucks, conveyor belts, and temporary materials can be used for the simulated construction. Since 2022, all excavators and dump trucks have been robotized and the participants aim to realize fully automated construction. The time, quality, cost, and automation level are evaluated as scores, and the group competition is held. Each group builds an original construction plan that can receive a higher score and develops motion programs for the model construction robots to realize the plan.

The most significant feature of this educational program is the integration of civil engineering and robotics, considering future construction sites. Participants can experience the process of creating new ideas and innovations through practice and competition, not only on the table, but also using real equipment, although they are models and simulated environments.

3 Development of Linking System Between Construction Planning and Model Construction Robots

The major issues revealed by the implementation of the educational program in 2022 and their improvements are summarized. Other improvements are not discussed in this study.

3.1 Issue and Improvement Method

Although some issues were revealed from the practices of the previous education program in 2022, the major issue was that the information in the developed construction plans could not be used directly for the operation of model construction robots. As mentioned previously, the layout of the construction equipment was planned by drawing maps on a PowerPoint file. For example, to make the

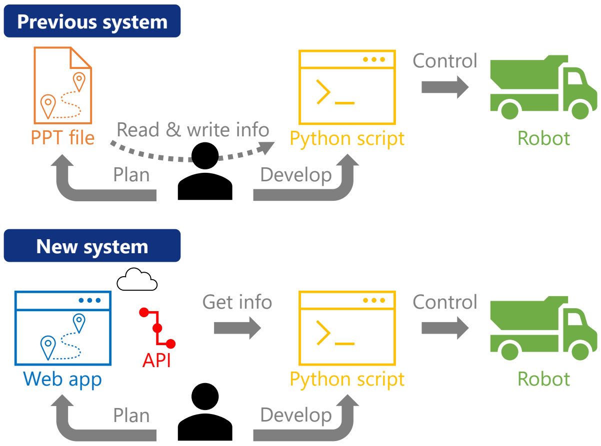

Figure 2. System for the education program

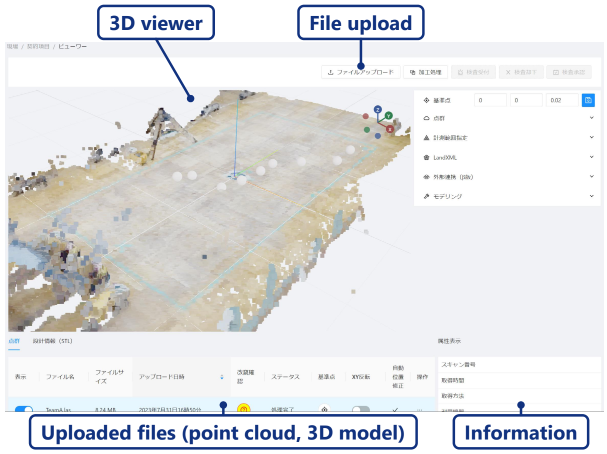

Figure 3. Operation screen of R-CDE

dump trucks follow a planned path using the implemented path-following control, it was necessary to develop control programs with hard-coded positions or paths based on the plan (upper side of Figure 2).

Therefore, a web application and an API (Application Programming Interface) are prepared to solve this issue. The web application is used for the layout planning of construction equipment. The API allows access to planned position or path information on the web application. This makes it possible to link the construction plan and model construction robots directly by developing programs that obtain information from the web application via the API and operate the model construction robots (lower side of Figure 2).

3.2 R-CDE and ServiceHUB

The R-CDE was used as a web application for construction planning, and ServiceHUB was used to link R-CDE and the model construction robots.

The R-CDE is a prototype of a common data platform for data and system collaboration in the construction phase, developed by the University of Tokyo and the Japan Federation of Construction Contractors [18]. This system visualizes the 3D models and 3D point clouds stored in the system.

ServiceHUB is a prototype API collaborative platform that links the R-CDE to various devices or applications. The API is implemented using the RESTful API. This allowed access to the above information of 3D models in the R-CDE.

These are web systems built on AWS. By connecting various applications and devices, such as total stations and GNSS on construction machines, to the R-CDE via the Internet and the ServiceHUB, information required for construction and inspection can be managed and shared. R-CDE also can be accessed through a browser (Figure 3).

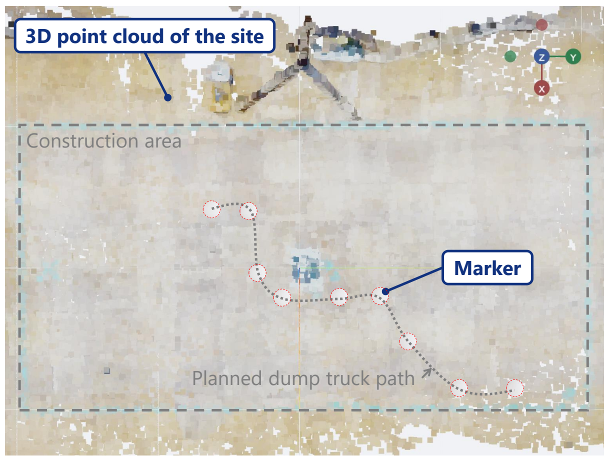

Figure 4. Details of the 3D viewer of R-CDE (top view)

From the browser, data can be uploaded and the information contained can be confirmed. In addition, a 3D viewer is provided to visualize uploaded 3D models and 3D point clouds. Users can place them in arbitrary positions in the 3D viewer.

In this educational program, the R-CDE is used to plan the layout of construction equipment. In addition, the information from the plan is directly used to control the model construction robot by connecting the R-CDE and the robot via the ServiceHUB. Specifically, first, a 3D point cloud of the simulated construction site is displayed on a 3D viewer of the R-CDE. Second, 3D models of a marker representing a robot's position and path, such as a sphere or cone, are placed at arbitrary positions on the 3D point cloud to plan the layout and path of the construction equipment (Figure 4). Third, the programs to control the robots send API requests to the ServiceHUB as needed and receive the marker position information in the R-CDE as a response. Finally, the received information is used to move the robots.

4 Demonstration of the Developed System

The improved education program was conducted as a four-day intensive course at the University of Tokyo from July 31 to August 3, 2023. A system that links construction planning and model construction robots was demonstrated in this educational program. The prepared system and results of the demonstration are explained.

4.1 Prepared System

The system was prepared as follows.

- R-CDE and ServiceHUB
- Model construction robots
- PC
- Wireless LAN router

The R-CDE and ServiceHUB were built on AWS (Amazon Web Services). The model construction robot and PC were built using Ubuntu 20.04 LTS and ROS 2 Foxy, and connected to the same wireless LAN router. Programs to control the model construction robots were developed and executed on a PC. Moreover, the wireless LAN router was connected to the Internet via a mobile network. While creating a construction plan, the participants accessed the R-CDE from a web browser on a PC. When linking the construction plan and model construction robot, information on the R-CDE was obtained from the control program of the model construction robots via ServiceHUB. Because the educational program was conducted in three groups, three sets of this system were prepared.

4.2 Results

The methods used to obtain information on R-CDE via ServiceHUB in this educational program can be roughly divided into the following three methods.

1. From Postman
2. From Python scripts on Google Colaboratory
3. From Python scripts to control the model construction robots on the PC

Method 1 is a test to check the access and learn the mechanics of the API. The Postman is a platform for using or developing API. Method 2 is performed to learn how to access the API from a Python script. Method 3 connects the system to the model construction robots.

In Methods 1 and 2, information on the R-CDE can be obtained through ServiceHUB by sending requests. We confirmed that the R-CDE and ServiceHUB functioned normally.

Method 3 can be realized by integrating Method 2 into Python scripts to control the model construction robots. Note that the implementation of Method 3 and the use of the obtained information were not directly instructed and were left to the participants in the education program. One group developed a program that first performed API access when the program ran, obtained the position information of a group of markers placed on the R-CDE, and used it as a path for the dump truck. Although there were differences in usage, the developed system worked as intended, and the construction planning and model construction robots were integrated.

However, it is necessary to improve the usability of R-CDE. In particular, it seems difficult to arrange markers indicating the paths of dump trucks.

This system makes it possible to link the layout or route plan in the construction plan, i.e., the position information, to construction robots. However, there is other important information in the construction plan and control of construction robots, such as the timing or triggering of motion. Planning it in a system and linking it to construction robots is a topic for future work.

When focusing on the construction plans of each group, all groups built plans using only model construction robots in 2023, although there were differences in the details. Some groups used belt conveyors or bridges made of temporary materials until 2022. Thus, the variety of construction plans was reduced. The reduced variety may be because the participants concentrated on the software development of the construction robot and there was not enough time to create ideas for the construction plan. This was related to the fact that, unlike in previous years, the construction robot programming was taught first, followed by the construction planning. The additional development topics, such as API access, also affected it. Thus, the structure and duration of the educational program should be reconsidered.

5 Conclusion

This study describes the development of a system that links construction planning and construction robots for civil engineering and robotics-integrated education programs. To create innovations or ideas in an environment closer to future automated construction sites, where information, communication, and robot technologies are linked, a web application for construction planning was built and linked to model construction robots through API. Although some issues were identified, the developed system worked as intended.

In future, by solving the aforementioned issues, an environment in which participants can concentrate more on creating ideas for construction must be established. Furthermore, a similar setup to that of full-scale construction robots is provided, and the content is expanded to connect to real construction sites. The final goal is to improve construction sites by applying the valuable ideas obtained through this educational program to real construction sites.

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