REMOTE CONSTRUCTION EXPERIMENT FOR UTILIZING WATER RESOURCES ON THE MOON.

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Introduction: In the early stages of resource reutilization on the Moon, staying on the lunar surface and manually operating complex construction machinery will be difficult for many astronauts (or workers). Unmanned construction machinery is considered an effective solution to overcome this difficulty, and therefore, there is a need to develop remote control and automatic operation technologies. These technologies are also required on the Earth given the decline in the number of workers employed at construction and civil engineering sites. To solve this common problem in space and on earth, the Japan Aerospace Exploration Agency (JAXA) has been working with a construction company to develop technologies for constructing lunar bases and for lunar resource utilization [1,2]. In this study, we developed a remote control and automatic operation system for construction machinery and performed demonstration experiments for a water resource utilization scenario on the Moon.

Water resource utilization scenario on the Moon: JAXA's international space exploration scenario presents a process for extracting water resources on the Moon (Figure 1) [3]. It is believed that water is trapped in the regolith located in the permanent shadow area inside craters near the lunar South Pole. Various construction machines would be required to obtain this water. The process would involve excavating the regolith that contains water using backhoes inside the crater. Then, the regolith will be loaded onto a crawler carrier and transported to a fuel generation plant in the sunlit area outside the crater. This sequence will be repeated, and the fuel, i.e., oxygen and hydrogen, will be generated from the transported regolith at the plant. The generated fuel will be used for lunar landers and for lunar resource utilization.

Demonstration experiment using construction machinery: We conducted demonstration experiments to validate the feasibility of a water resource utilization scenario using unmanned construction machineries. The experiment investigated the effectiveness of the remote control and automatic operation system of the machinery. The overview of the construction machinery used, remote operation system, and experiments are described below.

Construction machinery system. Figures 2 and 3 show the hydraulic backhoes and crawler carrier modified for remote control via electronic signals. Cameras, a global positioning system (GPS), and a laser range finder were installed on the backhoes and the carrier. The position of the machineries can be estimated while constructing a 3D map of the surrounding environment. Inclinometers were mounted the boom, arm, and bucket of the backhoes to measure their rotation angles.

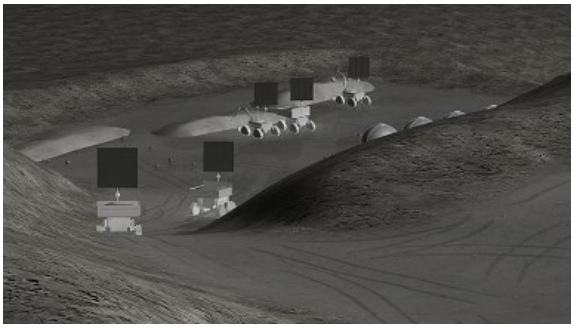
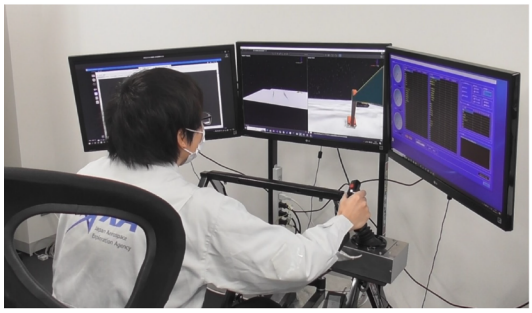


Figure 1 Water resource utilization scenario on the Moon.

Figure 2 Remote-controlled backhoe.

Figure 3 Remote-controlled crawler carrier.



Console that comprises three monitors and joystick controller

Dynamic simulation of the machineries

Command/telemetry data

Figure 4 Remote control system for construction machinery.

Figure 5 Demonstration experiment using two backhoes (BHs) and crawler carrier (CC).

Remote control system. The backhoes and crawler carrier were operated remotely from a console located away from the construction field. Figure 4 shows the console that comprises three monitors and joystick controller. The video image obtained from the cameras mounted on the machineries, dynamic simulation of the machineries, and command/telemetry data are displayed on the monitors. The dynamic models of the machineries are displayed on the simulation monitor. These models are driven based on the commands sent to the actual machineries. The simulation results help an operator to better understand the motion of the machineries. The command submitted to each machinery and the telemetry received from them are displayed on the command and telemetry monitor. The operator operates the construction machineries from a remote location using the information displayed on the screens. This operation is performed via manual control using a joystick or by sending sequential automatic operation commands.

Overview of the experiment. Demonstration experiments were conducted using two backhoes and a crawler carrier in the construction field (Figure 5). In the field, the upper and lower levels imitate the inside and outside regions, respectively, of the crater on the Moon. The machineries were controlled via a console located dozens of kilometers away from the field. In the experiments, one backhoe (i.e., BH1) was remotely controlled and moved from the upper to the lower level through a slope connecting the levels. After the backhoe reached the target region in the lower level, it roughly excavated and loosened the ground surface automatically. Subsequently, another backhoe (i.e., BH2), which stayed in the region, scooped the loosened sand automatically and loaded them onto the crawler carrier (i.e., CC). The CC transported this sand from the lower level to the upper level. This construction sequences was repeated many times via automatic operation. The demonstration experiment confirmed the feasibility of the water utilization scenario by effectively using remote and automatic control technology for the construction machinery.

References:

[1] JAXA. “The JAXA Space Exploration Innovation Hub Center Co-Produces Results on Remote and Automatic Control to Build Lunar Base,” https://global.jaxa.jp/press/2019/03/20190328a.html, (accessed on March 29, 2023).

[2] Kajima. “A^{4}CSEL for Space,” https://www.kajima.co.jp/english/tech/c_a4csel/space/index.html, (accessed on March 29, 2023) .

[3] JAXA. “JAXA’s International Space Exploration Scenario (in Japanese)” (accessed on March 29, 2023).