Introduction of Products

Large Bulldozer Teleoperation System KFTDZ-1

Souichi Tsumura

We have developed and launched to the market a teleoperation specification of large bulldozers (D375AI-8 and D475AI-8) equipped with an automatic blade control function (ICT function), and a remote control console (KFTDZ-1). This paper reports on the main features of the product.

Key Words: *Bulldozer, Information-based construction, Intelligent machine control, Teleoperation*

1. Introduction

Demand for teleoperation is growing rapidly in the mining business, aiming to ensure safety. Besides, securing skilled operators has become an issue at each mine.

To solve this issue, Komatsu has developed a teleoperation system for large bulldozers that automatically controls the blade, which is difficult to operate remotely, allowing even unskilled operators to use the system remotely. The details of this teleoperation system are as follows.

2. Overview of the teleoperation system

2.1 System configuration

We have developed a teleoperation system based on a line of sight radio-controlled machine. We have owned remotely controllable machines that allow teleoperation by visually checking the behavior of the machine. However, it was operated only in a condition that the work equipment, machine body, and terrain were within the operator's visual range. We have realized teleoperation from a long distance using an Ethernet line by developing a video transmission function using on-board cameras and a function to transmit operation signals from a teleoperation room. The configuration of this system is outlined in **Fig. 1**.

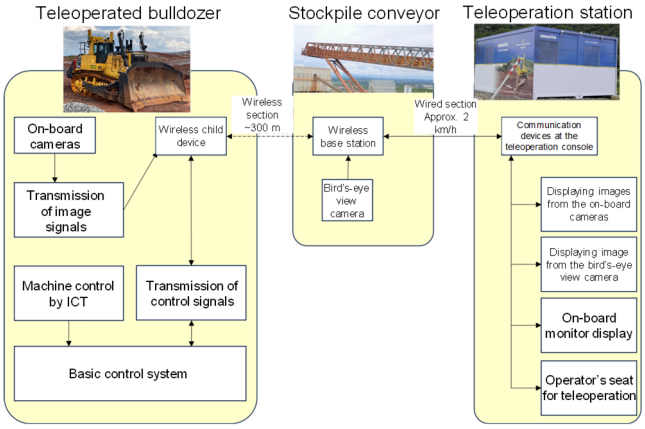

Fig. 1 System configuration

2.2 On-board camera

A bulldozer has two work equipment: a blade in the front for pushing soil and a ripper in the rear for digging up rocks. Its two main works are dozing, using the front blade, and ripping, using the rear ripper. With another work of moving (driving) to the operation site added, bulldozer work can be broadly classified into three types.

In developing the teleoperation system, a total of eight cameras were mounted to ensure proper operations in the three types of work (**Fig. 2**).

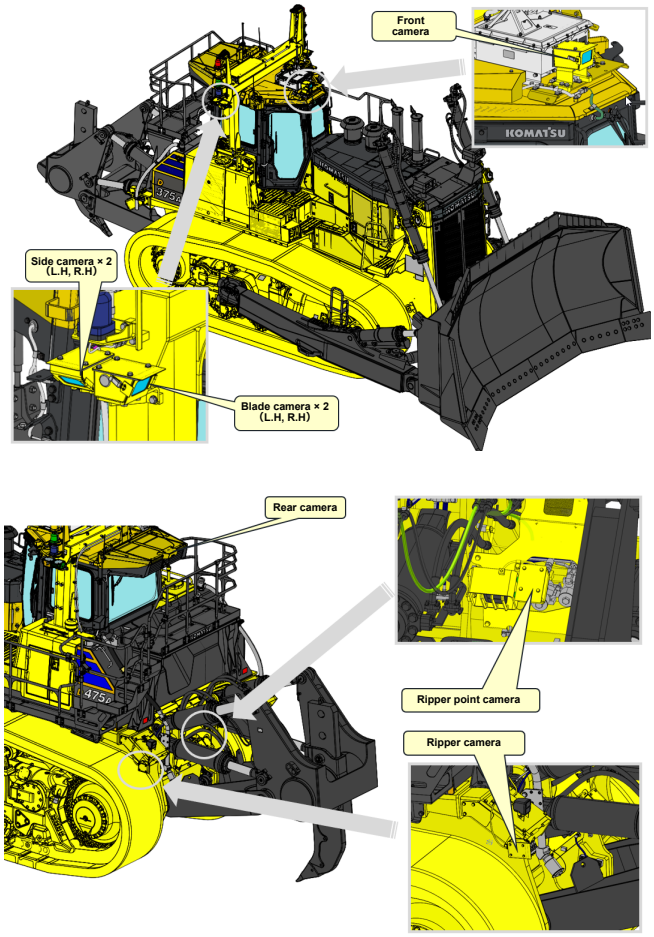

Fig. 2 On-board camera

Four cameras were selected according to each work mode and videos were transmitted to the teleoperation room to provide on-board images optimal for each work while reducing communication volume.

When driving the machine, the operator needs to check the positional relationship between the machine body and the surrounding situation; therefore, the driving screen secures a 360-degree field of view, excluding obstruction by the own machine (**Fig. 3**).

The dozing screen (**Fig. 4**) focuses on the vicinity of the blade in order for the operator to identify the situation of soil spilling from the blade and the terrain in front of the machine body. Because identifying the tilt of the machine body is difficult using the videos only, a clinometer is displayed in the center of images to facilitate the identification of the machine posture.

The ripping screen (**Fig. 5**) shows the position of the ripper, which is not visible even while the operator is on board, in top and side views so that the operator can easily identify the angle of the ripper and the position of the ground where the ripper is to be inserted.

Fig. 3 Driving screen

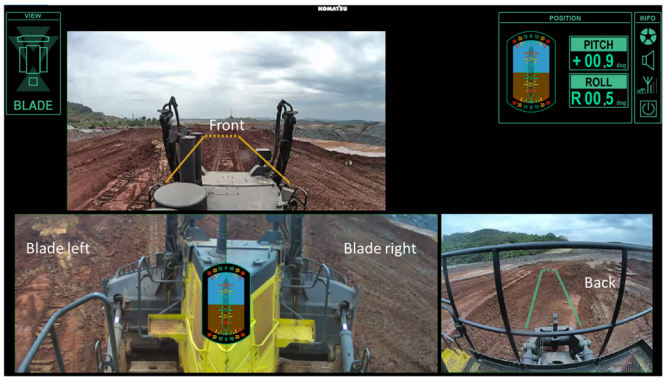

Fig. 4 Dozing screen

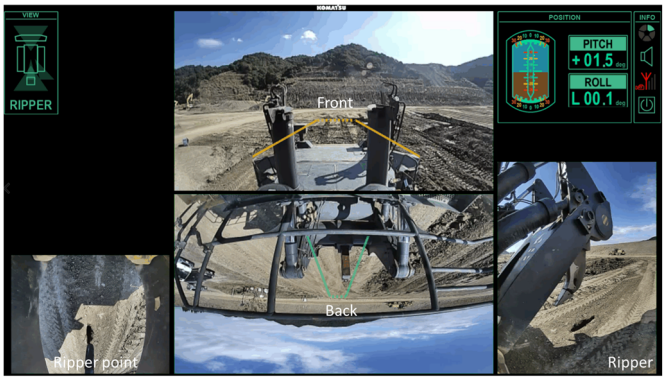

Fig. 5 Ripping screen

2.3 Teleoperation console

We tried to ensure that the teleoperation console (**Fig. 6**) replicates the environment of a machine cabin so as not to impair the operator's sense of control.

For visual display, the on-board camera monitor mentioned earlier, the machine monitor in the cabin, and the ICT monitor were remotely displayed. Depending on the use case, the sense of distance may lack during teleoperation. When a bird's-eye view camera was used to assist it, a bird's-eye view camera monitor was used with the on-board camera monitor placed together.

For the operation system, we used the same levers and pedals as the ones on board. We set up an environment that achieves teleoperation without any sense of discomfort by picking up the sound of operation from the on-board microphone and reproducing it on the loudspeaker in the teleoperation room.

For the controllers, we used a controller area network (hereinafter referred to as "CAN") similar to the on-board controller and added a newly developed translation controller to the CAN to convert CAN signals into Ethernet signals. The control signals converted to Ethernet signals are sent to the machine via communication devices and are then reconverted to CAN signals by the translation controller mounted on the machine.

The use of Ethernet for communication between the machine and the teleoperation room eliminates limitations of distance and enables ultra-teleoperation.

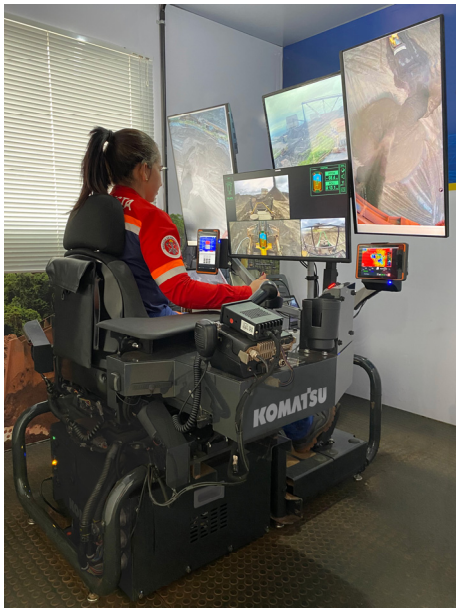

Fig. 6 Teleoperation console

2.4 Automatic blade control function (ICT function)

As a trade-off, a teleoperation system inevitably causes a delay between the operation system and the video system. This makes it difficult to apply the teleoperation system to land-leveling work and slope-grading work, which require delicate blade operation, thus reducing workability. Deteriorated operability of bulldozer's work equipment is a factor that significantly decreases productivity.

ICT functions are available as mainstream means of compensating for reduced productivity in small and medium bulldozers. We realized an ICT function for large bulldozers for mines by linking it with the machine guidance system ProVision developed by MMS (**Fig. 7**). To use the ICT function, topographic data called design surface data needs to be created and input into the ProVision system in advance. The operator can simply create design surface data (10% slope, finite plane, etc.) via the machine guidance remote monitor located nearby (**Fig. 8**).

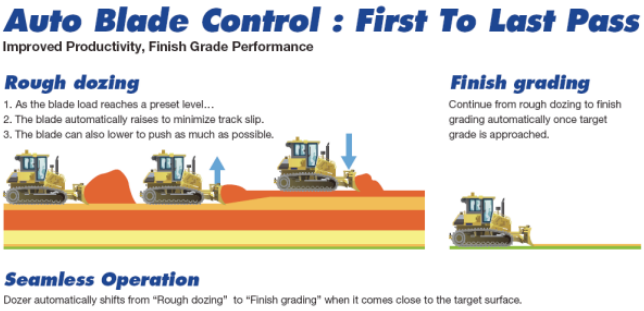

Fig. 7 Operations from heavy-duty excavation work to land-levelling work are possible

Fig. 8 ProVision monitor screen

3. Deployment of the teleoperation system and operation support activities

The environment of mining sites differs in many ways from the in-house development and testing environment. Starting up the developed remote system at the site requires careful preparation with the customer through several advance preparatory phases. They consist of four phases: (1) Assessment phase (formulation of rules for on-site customer operation, network policy, hazard analysis, etc.), (2) System start-up and commissioning phase, (3) Training phase (for site managers and operators), and (4) Operation phase at the actual production site. Advancing in each phase requires the understanding of the customer's current operations at first (how bulldozers are used at the site, operating environment including dust generation, communication infrastructure, etc.) and then formulating new operation rules based on the results of hazard analysis (installation of signages, rules for approaching machines, procedures for changing operators, etc.). Those procedures proceed through multiple discussions with the customer's technical team, and efforts must be made jointly with the customer to ensure stable operations. The following is an example of one of the activities that most affect the utilization rate of teleoperation: communication infrastructure construction activities.

- On-site support during deployment: construction of telecommunications infrastructure for teleoperation

Multiple management systems are constantly operating at mining sites, and communication between the operation management room and each mining machine is performed typically via communication infrastructure facilities owned and maintained by the customer. In order to operate the newly developed teleoperation system in the customer's telecommunication infrastructure, it was necessary to construct a communication infrastructure by carefully coordinating with the customer's technical team through the presentation of system requirements and solution proposals to (1) Ensure sufficient communication bandwidth, (2) Stabilize communication performance, and (3) Establish communication coverage over the teleoperation area.

4. Results and outcomes of demonstration test

After going through these phases, we began a full-scale operation of the teleoperation system at the customer's stockpile. Located between the secondary crushing plant and the beneficiation plant, this stockpile is one of the key facilities for production activities in mines, where temporarily stocked ore is dropped into the feeder by bulldozers and supplied to downstream processes. In proceeding with teleoperation, we set multiple KPIs for productivity and safety after consulting with the customer and performed monitoring during the trial period, which achieved outcomes outperforming the target values for all KPIs.

The following values have been realized through our support for the teleoperation system, where we had close consultation with the customer, resulting in high evaluation by the customer.

- Improved workability around feeder due to the bird's-eye view camera installed on conveyors
- Improved visibility around the machine body due to images from multiple machine cameras
- Freeing operators from high-vibration environments
- Utilize a diversity of people as operators (e.g., regardless of gender, physical strength, or physical disabilities)
- Increased production through simultaneous operation of conveyor and remotely controllable bulldozer

Operations at the stockpile include slope-grading work for entry to the stockpile in addition to the work of dropping ore into the feeder. Currently, the automatic blade control function has been fully employed for those series of operations, facilitating teleoperation by the customer.

5. Conclusion

Post-sales support for automated and teleoperation systems is more important than ever. The teleoperation system introduced in this paper is also in an fast-evolving field, so we will continue to strive to build a development and support system that can respond quickly to current trends and customer needs to become indispensable to our customers.

Introduction of the author

Souichi Tsumura
Joined Komatsu Ltd. in 1993.
Bulldozer Development Group,
Vehicle Development Center 2,
Development Division

[A comment from the author]

We launched the automation and teleoperation technologies demanded by mines, albeit late compared to our competitors. This development would not have been possible without the cooperation of everyone involved.

I would like to thank each of you and express my deepest gratitude to you. All the departments involved will continue to work together to expand the market and support our customers.