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Development of a Tele-earthwork System

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Abstract

The tele-earthwork system we have developed is able to remotely control unmanned power shovels and unmanned crawler dump trucks, and a series of unmanned operations ranging from excavation to transportation. The results of our demonstration tests proved that the tele-earthwork system is capable of performing remote-control operations at a point 1 kilometer or more away from construction sites, and its working efficiency through remote-control operation is approximately 0.4 lower than manned work.

1. INTRODUCTION

In recent years the shortage of skilled construction workers and technicians has become increasingly serious. This situation is made worse by the extremely small number of young people who want to work for the construction industry and the aging of the present work force. Earthwork sites are no exception, and a shortage of earth-moving machine operators has just begun. This demands civil engineering contractors to use earth-moving machines requiring less labor and further rationalization of earthwork. Unless work environments are rapidly improved by liberating construction workers from difficult, awkward, dangerous work, the construction industry in Japan will not have a promising future, which could create serious social problems.

In recent years the development of electronics and mechatronics has been noticeable, and incorporation of most advanced technologies derived from studies in these fields has made it possible to automate and robotize construction machines. Having recognized this, we wasted no time in introducing hi-tech engineering into construction work, and since then have carried out a diversity of aggressive attempts to realize automated as well labor-saving construction work. With the aim of improving working environments and liberating workers from dangerous work at civil engineering work sites, we have developed this tele-earthwork system, which can control a series of work ranging from excavation to transportation through an ultra-remote operation system in a control room located away from the work site where unmanned earth-moving machines are in operation. This paper outlines the tele-earthwork system and discusses the field tests carried out to prove its effectiveness and work performing ability.

2. SYSTEM OUTLINE

The tele-earthwork system is composed of a teleoperation system and a work support system (Figure 1-1), which uses 50GHz-band hand-held radios and specific low-power radios. With these, the system controls earth-moving machines and other construction equipment in real time from a point a few kilometers away from the site. The work support system controls excavation, the progress of work, the amount of work completed, and the construction schedule.

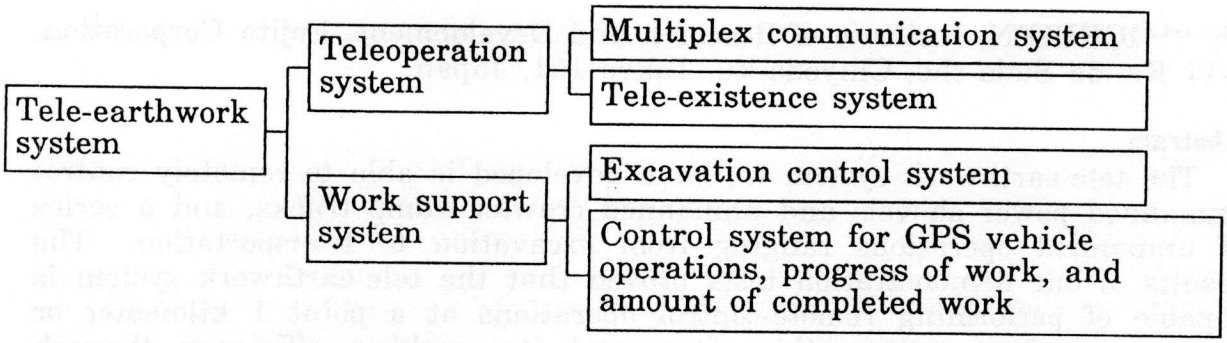

Figure 1-1. Tele-earthwork system configuration.

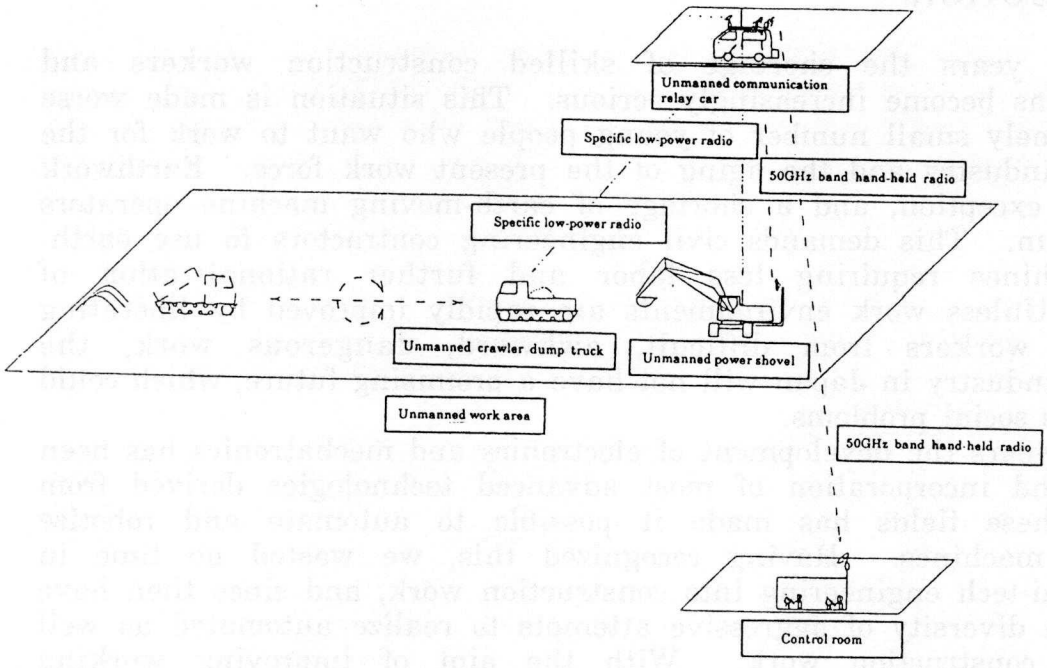

Figure 1-2. Tele-earthwork system outline.

The excavation control system calculates the three-dimensional attitudes and positions of earth-moving machines, and visually displays desired

excavation lines on the operator's monitor. The system performs these functions based on the data of the earth-moving machines obtained from automatic tracking measurements taken remotely from the total station on the site, and on the data of the articulated angles detected by the built-up sensor of each earth-moving machine.

With the tele-earthwork system, the crawler dump truck, the power shovel and the monitor cameras in a work area are remotely controlled to do excavation, loading and transportation through the unmanned communication relay car, which receives commands from the control room located a few kilometers away from the site, as illustrated in Figure 1-2.

2.1. Teleoperation System

Figure 1-2 outlines the teleoperation system. With this system, the remote control of excavation, loading and transportation performed by earth-moving machines can be conducted from the control room a few kilometers away from the site. The multiplex communication system transmits control data and visual information required to do remote controlling, and the tele-existence system remotely controls earth-moving work through the visual information transmitted.

Visual information (such as three-dimensional pictures, pictures taken by the monitor cameras, and other control pictures), which is required to ensure remote operations, is transmitted to the control room from the communication relay car stationed on the unmanned work site through the 50GHz-band hand-held radios. Machine operators can operate their earth-moving machines remotely while watching the visual information.

2.1.1. Multiplex Communication System

The multiplex communication system transmits control data and visual information. Table 1 classifies the patterns of communications.

Table 1.
Classification of area communications by the tele-earthwork system.

	Communication pattern	Unmanned communication relay car	Communicable distance
Control room	Visual	50GHz-band hand-held radio	3km
	Control data	50GHz-band hand-held radio	3km
Power shovel	Visual	50GHz-band hand-held radio	3km
	Control data	Specific low-power radio	200m
Crawler dump truck	Control data	Specific low-power radio	200m

① Communication between the control room and the communication relay car

Control data and visual information is transmitted from the relay car to the control room via the 50GHz hand-held radios. The communicable distance is approximately three kilometers where the working area affords

an unobstructed view. Transmission to over three kilometers is possible if information is relayed more frequently through the hand-held radios.

② Communication between the relay car and earth-moving machines

Communication between the relay car and each earth-moving machines is transmitted through the specific low-power radios. The communicable distance in this case is about 200 meters.

③ Communication of visual information from the earth-moving machine camera

To perform excavation and unloading that requires extreme care, the operator has to manipulate his machine while he watches the three-dimensional information displayed on his monitor in the cab. Three-dimensional pictures displayed on the earth-moving machine camera are transmitted to the control room through the relay car via the 50GHz hand-held radio.

④ Multiplex communication

With 50GHz hand-held radios, the number of channels allocated is restricted by the Wireless Telegraphy Code of Japan (in our case, ten channels per five pairs of radios). To cope with this, we use a multiplex communication system that permits more than two machine operators to remotely and bidirectionally control their machine operations by sharing one channel of the 50GHz hand-held radio.

2.1.2 Tele-existence System

In the case of transportation of excavated material by the unmanned crawler dump truck, carrying it out remotely from a point a few kilometers away from the site is possible with the operator watching the pictures displayed on the camera set outside the work area. However, in the case of excavation by the unmanned power shovel, it requires remote controlling in virtual reality through pictures displayed on the machine camera. To permit detailed work to be carried out remotely, we have developed the tele-existence system and used it to control three-dimensional pictures and computer graphics (Figure 2).

① Stereoscopic cameras

There is a set of four cameras in the housing of the machine camera. The cameras are of two types and each camera has a fixed focus and a different focal length. These cameras transmit three-dimensional pictures to the control room via the unmanned relay car. The cameras can be selected and switched over remotely from the control room.

② Transmission of pictures

Two pictures, each reflected by the right and the left cameras mounted on the earth-moving machine, are condensed to form a single picture, which is then transmitted to the control room via the hand-held radio and the relay car. In the control room the pictures are then redisplayed on the computer screen by using a liquid shutter change-over unit.

③ Operational environment

Machine operators perform remote operation in virtual reality by using three-dimensional pictures, and noise (generated from engines, etc.) picked up by a directional microphone. This provides the operator with the feeling as if he were in the machine. Also, based on the data of the articulated

angles of the machine which has been transmitted to the control room, the three-dimensional computer graphics of the machine are displayed in real time on the control monitor. This enables the operator to determine objectively the attitude of the entire machine, which makes it possible for him to operate the machine with the feeling of presence. In addition, the excavation control system is linked to three-dimensional computer graphics, which automatically displays the desired excavation line in virtual space. Thus, the operator, in the virtual space of the control room, is able to remotely perform excavation to the specified depth and the loading of the excavated material on the dump truck.

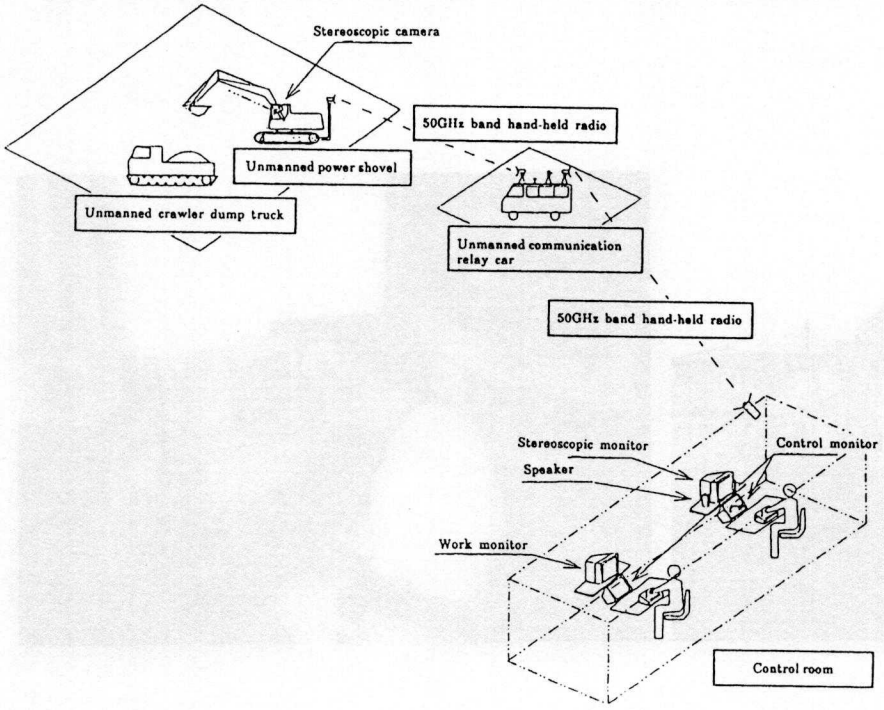

Figure 2. Tele-existence system control.

3. DEMONSTRATION TESTS OF THE TELE-EARTHWORK SYSTEM

The effectiveness of the elements of the system were varified through various field tests. However, to improve the utility of the system, we conducted operation tests on an actual construction site to verify the following principal items:

① Communication performance over the ultra-remote distance of 1 kilometer or more, and
② Maneuverability and working efficiency of earth-moving machines by ultra-remote control.

3.1. Outline of Tests

The demonstration test of the tele-earthwork system was carried out at an actual site in Chiba Prefecture. The system was set up so the test area

(where enclosed in the figure), the power shovel, the crawler dump truck and the communication relay car were arranged as illustrated in Figure 1-2. These machines were completely controlled through the control room. Sections subjected to communication are as classified in Table 1. The power shovel excavated the undisturbed ground as instructed remotely from the control room while the operator watched three-dimensional pictures, and the crawler dump truck hauled the excavated material from a designated place. Based on pictures reflected by the monitor camera of the relay car on the site, all work was monitored and the crawler dump truck was operated. In Photos 1 and 2, the loading of excavated material into the dump truck and the state of operations being performed on the testing area of the site are shown.

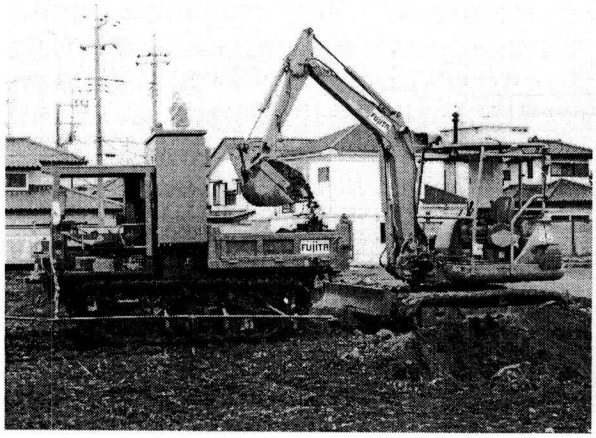

Photo 1 Loading operation is taking place.

Photo 2 The state of operation in progress.

3.2. Test Results

During the tests, all data was able to be transmitted without delay. However, if more machines are used, communication control functions should be augmented, such as automatically changing-over communication circuits.

Operation of the crawler dump truck was done only through pictures reflected by the monitor camera mounted on the relay car. To provide better efficiency in remote controlling, a study must be conducted of the number of work monitoring cameras, their effective arrangement, including setting positions, and the use of a mobile camera car. Further, to improve the operational efficiency of the shower shovel, more visible, stereoscopic operation pictures and wider pictures are required. A study on other method of transmitting pictures is necessary as well.

Through measurements of the cycle times and the volume of excavated material, we derived the work efficiency figures shown in Table 2.

Table 2.
Work efficiency of unmanned earth-moving machines (manned work efficiency is assumed to be 1.0)

Work classification	Work efficiency through remote operation
A series of work: excavation, loading, transportation to unloading	0.4
Excavation to loading by power shovel	0.4
Transportation to dumping by crawler dump truck	0.5

4. CONCLUSION

We are now developing earth-moving machines that are larger than those used for this development to create a better tele-earthwork system with greater reliability, including its associated hardware and software systems. To this end, we are repeating the necessary tests.