Development of Simple Attachment for Remote Control (DokaTouch)

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Abstract –

The development of the DokaRobo series for remotely controlling construction equipment began in 2007, and life-size humanoid robots (The DokaRobo No. 1 and 2) were developed. The DokaRobo series is installed in the driver's seat and can be easily installed by a single adult. After repeated tests and interviews with users, it was realized that the robot needs to be frequently switched between remote control and manned operation, and it is desirable to have a remote control unit that can be manned even when it is installed. The compact retrofit device "DokaTouch" was developed based on the concept that it would improve the work in the bad environment if an ordinary construction machine could be remote-controlled more easily. In this paper, the present configuration and functions of the DokaTouch are explained, and its application to the future construction site is reported.

Keywords –
Unmanned Construction Machinery; Internet; LTE

1 Introduction

In recent years, large-scale natural disasters have been occurring frequently, and there is a need for urgent and rapid recovery work to save lives and prevent secondary disasters. In addition, remotely operated construction equipment that can be used in a wide range of areas with multiple units is also needed. The greatest advantage of remotely operated construction machinery is that it can safely carry out unmanned construction work in adverse environments, such as disaster areas. However, it is also desirable to have an operator on board the machine for emergency or detailed work that is difficult to do by remote control. Therefore, it is necessary to secure the passenger space even if the remote control device is installed. In order to solve this problem, we have developed a remote-controlled construction machine by installing a compact actuator unit for each control device.

The system must be able to transport, install, and operate the equipment easily and smoothly to respond to emergencies such as disasters. In addition, it is necessary to reduce the discomfort of remote control by faithfully reproducing the operation with low latency. The biggest advantage of DokaTouch is that it is compact, lightweight, and highly functional, and can be used with general-purpose construction equipment that can be procured on site. In addition, the system allows the operator to use not only the operator's eye view from the cockpit, but also the overhead view of the machine. The operator can work remotely from a distance via the Internet, and can also use a control device that feeds back the sound, vibration and posture of the construction equipment.

DokaTouch is aiming to create an economical and easy-to-use remote control system by eliminating custom-made parts as much as possible. In the case of Internet connection, it is possible to monitor the operation status and assist the pilot, which will improve safety and reduce the shortage of operators. The inexpensive and highly functional control device "DokaTouch" will be widely used for construction work during normal operations. It can be used on a daily basis to speed up the recovery process in the event of a disaster.

This paper introduces an attachment-type remote-control actuator, "DokaTouch," which can be attached to the operating levers and pedals of general-purpose construction machinery to enable remote control.

2 Purpose of Development

Currently, remote control of construction equipment is meant to enable rapid recovery work in places where human life is at risk in the event of a disaster. To achieve this goal, the system must be able to respond to emergencies, but it is not realistic to have a dedicated

machine on standby for training in the event of a disaster, which is costly and unpredictable. In the future, we may see remote-controlled aircraft deployed to every corner of the country. Until then, it is necessary to install and use remote control devices whenever necessary.

Familiarity with the operation of a remote-controlled machine is a very useful experience in case of disaster. A remote-controlled system for on-site construction would be a good preparation for disaster response without special training. Therefore, a safe, easy-to-use, and inexpensive system is needed. Each disaster site has different conditions, and the working procedures and types of equipment used are different. For example, various types of machines such as excavation, loading, transportation, and land preparation will be required. The following is a list of requirements for the remote control system of construction machinery.

(1) Lightweight and easy to install, easy to transport the main body, and about half a day's installation time for two people.

(2) Easy to handle, general-purpose machines can be used as they are.

(3) Easy to set up and positional calibration can be done in a short time.

(4) The 3D image is easy to work with and to understand the site conditions.

(5) Compatible with various types of construction equipment, mainly shovels, but also crawler dumps, bulldozers, bulldozers and uneven terrain carriers.

(6) No radio qualification and application is required to use it.

(7) It is compatible with WIFI and internet connection.

3 Configuration of Dokatouch

3.1 Hardware Configuration

DokaTouch enables remote control of construction machinery by attaching an actuator to the control lever, pedal, switch, etc. and controlling them simultaneously. Fig 1 shows the photo of the backhoe. The retrofit actuators are compactly attached to the levers for both hands and feet. Fig. 2 shows a picture of the manned operation. Fig.3 shows the DT1 for a single axis. Fig.4 shows the DT2 for for two axis.

Since DokaTouch is a unit module, it does not require assembly work and can be used immediately by attaching it to each operating device. The drive unit is mainly a rotary type servo motor, but a stepping motor or linear actuator can also be used depending on the conditions of use. In addition to the drive unit, the system consists of a control unit, a communication unit, and a power supply unit, which is installed and fixed at the rear of the driver's seat. The power supply unit is powered by 24V DC from the battery of the construction equipment. A sub-battery can also be installed as an auxiliary power source. The frame of the drive unit is made of aluminum or CFRP (carbon fiber reinforced plastic) for a lightweight, strong structure. The use of CFRP prevents deformation due to impact and absorbs shocks during operation, transportation, installation and removal. Table 1 shows the specifications of DokaTouch.

Various types of DokaTouch are available, and they can be used for various types of construction machinery. Table 2 shows the various types of DokaTouch. The multi-functional joystick can also be used.

Figure 1. DokaTouch

Figure 2. With Operator

Figure 3. DT1

Figure 4. DT2

Table 1. Specification

Item	Content
Size	B300mm × L300mm × H250mm
Weight	1Axis : 1kg-3kg , 2Axis : 2kg-5kg
Power	DC24V , 300W(max)
Actuator	Servomotor , Stepping motor
Flame	Aluminum , Duralumin , CFRP

Table 2. Type of DokaTouch

TYPE	Operation part	Operation
DT1	Lever	1 Axis
DT2	Lever	2 Axis
DT3	Lever	3 Axis
DTP	Pedal	1 Axis
DTH	Handle	1 Axis
DTK	Rotary switch	3 Points
DTD	Dial	Any position
DTS	Push-button switch	1 Axis
DTR	Relay switch	1 Axis

3.1.1 SW Servo Type

Several servo motors are mounted on the upper part of the joystick, and each switch is pressed by a lever connected to each servo horn. Fig.5 shows the small servo motor attached to the switch.

Pros:

- Good response time.
- The servo motor allows a stepless setting.
- Installation is easy when using a servo unit.
- Each switch is equipped with an individual servo motor and can be operated simultaneously.

Cons:

- Difficult to operate with the switch installed. (Lighter servos with back drives can be used.)

3.1.2 Thumb Robot Type

The joystick is operated with a 3-axis robot attached to the top of the switch. Fig.6 shows a joystick with a thumb-robot attached.

Pros:

- Multiple switches can be operated by indicating their positions.
- The servo motor allows a stepless setting.
- Manned operation is possible with the device attached. (The device is placed in a position where it will not interfere with button operation.)

Cons:

- Simultaneous operation of multiple buttons is not possible.
- Responsiveness is not as good as that of the direct-attached servo motor type.

3.1.3 Wire Actuation Type

A wire-driven switch operating device is attached to the top of the switch on the joystick. Fig.7 shows the wire-driven joystick.

Pros:

- The light weight of the device makes it resistant to vibration.
- The servo motor can be used for a stepless setting.
- The servo motor unit can be made waterproof.
- Easy installation and removal of the device.
- Can be operated while mounted.

Cons:

- Responsiveness is worse than the direct servo motor type due to the elongation of the wire.
- Wiring space is required.

Figure 5. SW Servo Type

Figure 6. Thumb Robot Type

Figure 7. Wire Actuation Type

3.2 System Configuration

The system configuration of DokaTouch is shown in Fig.8. The edge PC processes the camera image and communicates with the network. The microcomputer acquires sensor data from IMU, etc., and controls the actuator based on the operator's operation information. The microcomputer is connected to the edge PC via serial communication. The network configuration of DokaTouch is shown in Fig.9. DokaTouch is connected to the server on the Internet, and it can be accessed by

any device that can use a browser, regardless of whether it is a PC or a smartphone. WebRTC is used for the video system, and MQTT is used for the operation commands, and the HTTP server is used for the GUI.

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3.3 Software Configuration

The main control unit consists of an edge PC and a microcontroller, and various functions can be added to the system. This system has the following functions.

- Control the robot using a joystick, and remote control via the Internet.
- Remote control through the Internet.
- Grasping the posture of construction machinery using a gyro sensor attached to the robot.
- Camera tracking using a gyro sensor attached to the operator's head.
- 3D display of binocular camera images using a head-mounted display.

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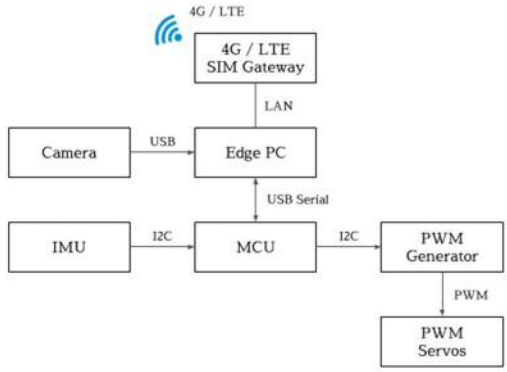

Figure 8. System Configuration

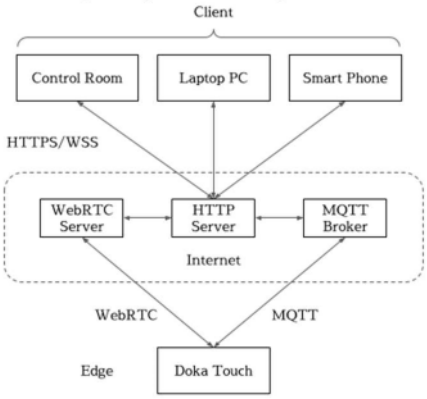

Figure 9. Software Configuration

4 Features of DokaTouch

DokaTouch can be installed in the driver's seat of general-purpose construction equipment when and where it is needed. This system allows work to be performed by remote control from a safe location. The features of this system are safety, small size and lightweight, and high performance.

4.1 Hardware Configuration

A small servo motor of 60 watts or less is used to ensure safe operation. The main drive unit uses one or two DC servomotors with a maximum torque of 100kg-cm, connected and linked to each other. One servo motor is used for each axis, and multiple axes can be used by combining units. The standby current at startup is 2A or less, and about 12A at maximum during operation. The turn-on/off of the safety lever of the machine is controlled by a separate circuit. In an emergency, the safety lever can be operated independently..

4.2 Software Safety

A software multi-safety system is used. To ensure safe operation, several measures are taken. First, each servo motor can be set to have a range of motion. To prevent the levers and pedals from rotating at unexpected angles and damaging the motors, the rotatable angle range is set for each servo motor in advance. This value is stored in the flash memory in each servo motor. Next, the maximum torque setting is set at a lower value for joints that do not require the torque of the servo motor to prevent the possibility of damaging surrounding objects when they move in an unexpected manner. Finally, as a countermeasure for communication errors, a function to stop at a safe position if communication is lost is provided.

4.3 Easy Install

Each device is small and light enough to be carried in the driver's seat by one person. The weight of the single-shaft type is about 2 kg, and the weight of the two-shaft type is about 4 kg. This is because it would be difficult for more than one person to work on the narrow driver's seat when it is installed over a door on one side. Since the equipment is dispersed, it can be transported in a small storage case in a car. Each device is fixed by using the armrest support part of the driver's seat and lever mounting bolts. Because they are attached to the existing levers as attachments, there is no need to remove any parts and no need to modify them. It takes one person about half a day to complete the installation and about two hours to dismantle it..

4.4 High Functionality

Our goal is to be able to use general-purpose machines at the site, regardless of the manufacturer or model. At present, the system can be installed on most of the backhoes, and we are planning to install it on the bulldozers and rugged terrain vehicles in the near future.

4.4.1 Any manufacturer or model

The conventional method of installing a device on the driver's seat makes it difficult to adapt to various types of construction machinery because the position of the levers (distance, height, and direction) is different for each machine. DokaTouch solves this problem by installing an actuator module directly to each lever. In addition, DokaTouch is very small, less than 300mm wide and 300mm long, so that it can be operated by a manned operator even when the equipment is installed.

4.4.2 User Friendly Interface

The remote-control unit is equipped with two operating levers (boom, arm, bucket, and slewing lever), two traveling levers (to move the crawler when moving), and button switches (to activate various operating motions). The maneuvering lever is controlled so that the target position of the work lever on the actual machine is calculated in response to the angle of fall and the operation is the same as at the time of boarding. Depending on the status of communication, there may be a delay, so the operator must pay attention to the delay. The gyroscope is installed in DokaTouch, and it is possible to prevent the machine from tipping over while working by grasping the inclination of the machine.

As an option, a bilateral operation system can be implemented, such as a rigid steering lever if the machine is in a dangerous condition. In addition, by attaching angle sensors to the operator's shoulders and arms, a master-slave operation system can be implemented to synchronize the arm movements with the bucket.

The operation situation from the control room is shown in Fig.10.

4.4.3 Easy calibration

Since the positions of levers and pedals must be taught to the operator after installation of the DokaTouch, positional calibration can be easily performed by the teaching function. After the machine is started up, the positions of the work lever, the traveling lever, and the foot pedal for the actual machine are taught by hand in the calibration mode. If the neutral position is fixed, move the movable range of each lever back and forth, left and right, and instruct it. After that, check if the operation is within the range of motion.

4.4.4 3D Head Mounted Display

Two FullHD (1920×1080) cameras are mounted on the head, which are converted to 3D images by a special device and transmitted. By using composite images, the amount of data can be reduced and the delay can be reduced. If the image is displayed on a head-mounted display, it is possible to feel a three-dimensional effect, which makes it easy to judge perspective and unevenness. By displaying the simulated image on the display, when an abnormality is detected, the part of the display changes to yellow or red depending on the alarm level, making it possible to check the abnormality while operating the system. Fig.11 shows a combined image from the binocular cameras. This image is displayed on the head-mounted display for each eye.

The camera head, which corresponds to the human head, has three axes of pitch, roll, and turn, and the gyroscope on the pilot's head enables the viewpoint tracking. The gyroscopic sensor on the head enables the pilot to track his or her viewpoints. A picture of the stereo camera is shown in Fig. 12.

4.4.5 Can be Operated via the Internet

The heavy equipment is equipped with a SIM that enables the use of mobile phone networks (4G/LTE). Therefore, if the machine is installed in an area where a mobile phone network is available, users can operate the machine from anywhere in Japan where they can access the Internet. Since the remote control and video transmission radios use the wireless LAN standard, no qualifications or licenses are required for radio operation.

4.4.6 Record and Play Mode

On a construction site, similar tasks may be repeated many times. To reduce the burden on the remote operator, a motion program can be created by recording the position data of the operating lever during the operation. For repeated operations, it is possible to activate the appropriate work motion to assist in the maneuvering.

Figure 10. Operation Room

Figure 11. Stereo Camera Images

Figure 12. Head Mounted Display

5 Issues and Future Development

At present, the efficiency of remote control by DokaTouch is about half of the efficiency of on-board operation. For the improvement of the efficiency, it is necessary to reduce the delay in operation and visual information between the operator and the actual device. Therefore, it is necessary to provide a reliable communication line. In order to supplement the visual information, the information of distance and ups and downs to be able to judge the working position and the surrounding situation is necessary. For this purpose, it is effective to display information on the screen from the operator's eye view of the camera or by installing a distance sensor or rangefinder on the machine itself. It is also possible to combine this information with XR (Mixed Reality) to provide an efficient work environment. By attaching sensors to the bends, it is possible to improve the operating environment while providing feedback on the condition of the construction machinery.

In the future, we must develop a system that is compatible with CIM (Construction Information Modeling) and allows multiple construction machines to work together.

6 Conclusion

We have developed DokaTouch, which can be remote-controlled safely and efficiently from anywhere in Japan, for use in dangerous construction work. DokaTouch is a compact and lightweight device that can be attached to each control unit of a general-purpose construction machine, and is equipped with an advanced software system. In the future, the system will be developed to control multiple construction machines and be expected to be used for various construction tasks.

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