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INTUITIVE OCU (Operator Control Unit) OF MFR (Multipurpose Field Robot) ON CONSTRUCTION SITE

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ABSTRACT

Recently, there has been a lot of interest concerning remote-control construction robot manipulation in hazardous operation environments including construction sites. However, there are problems involving the method of remote-control in unstructured work environments such as construction sites. In this study, an improved MFR system is described, which helps a human operator to easily install construction materials through an intuitive Operator Control Unit (OCU) on construction sites. The OCU consists of a force reflecting joystick and a vision system. The active compliance control and bilateral communication for strategic control is also described. In order to evaluate the proposed OCU, the installation of construction materials is simulated.

KEYWORDS

Intuitive, OCU (Operator Control Unit), Construction Site

1. INTRODUCTION

Recent research has found that a lack of skilled manpower in the construction industry is rapidly becoming a serious problem. One of the solutions suggested to solve these problems is robotization or automatic installation [1]. Since the late 1980s, construction robots have helped operators perform hazardous, tedious, and health-endangering tasks in heavy material handling. Isao et al. discussed the appropriateness of the automation technology for installation of a curtain wall [2]. Masatoshi et al. proposed the automated building interior finishing system and a suitable structural work method is described [3]. Lee et al. developed an automation system (ASCI; Automation System for Curtain Wall Installation) that is suitable for mechanized construction, which enables simpler and more precise installation than existing construction methods, while improving safety during installation [4].

Robots can be classified into two groups: those that can carry out work and coexist with humans in atypical environments unlike production factories, and those that do repeated work according to a standard program such as part assembly, or welding and coating in the automobile or electronics industries. In this discussion, a field robot is defined as one that executes orders while moving around in a dynamic environment where structures, operators, and equipment are constantly changing [5,6]. Until now, the development process of field robots has focused on the single-task robots, separate from planning to designing, production, testing, and inspection. This separation leads to the inefficient use of time and resources as well as to limited utility. In order to solve this problem, a Multipurpose Field Robot (MFR) is suggested, as shown in Figure 1 [7].

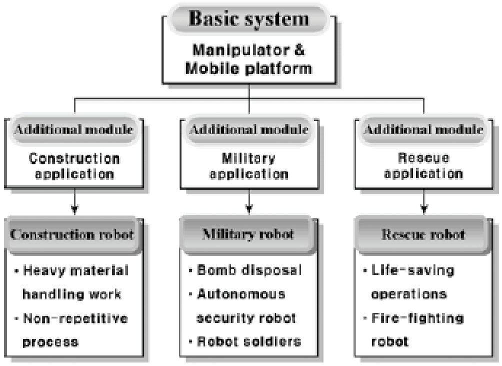

Figure 1 Framework of MFR

Construction robots are defined as field robots that execute orders while operating in a dynamic environment where structures, operators, and equipment are constantly changing. Therefore, a guidance or remote-controlled system is the natural way to implement construction robot manipulators [8, 9]. However, remote-controlled systems have to overcome some problems. For example, it is difficult to cope with malfunctions immediately when unexpected situations occur during construction work. In addition, it is difficult to gain environmental information for suitable operator commands.

In this paper, the intuitive Operator Control Unit (OCU) is introduced in order to solve these sorts of problems when the remote-controlled MFR is operated. The intuitive OCU consists of a force reflecting joystick and a monitoring device, which grasps the situation around the MFR. The control strategies are bilateral communication and active compliance control for smooth interaction between a human and a robot. Recently, an experiment related to installing the construction materials was executed by applying the proposed intuitive OCU to the MFR system.

2. MFR SYSTEM PROBLEMS

The MFR system was developed by Lee et al.[7] for installing heavy construction materials. The MFR system combines a basic system with an additional module for construction. Considering the workspace and mobility, a 6DOF manipulator and a 3DOF mobile platform were suggested for use in the basic system. Moreover, it is possible to change the elements of the basic system according to load specifications. An additional module, which is used for construction work along with various devices, is suggested to incorporate the MFR in construction work. It consists of hardware (HRI: Human-Robot Interface) and software (HRC control: Human- Robot Cooperative control). This system was used in experiments for installing construction material. Figure 2 shows the MFR system that consists of the basic system and the additional module for construction work.

Figure 3 shows a simulation of the installation of construction materials with the proposed MFR system. The operator manipulates the HRI device near the MFR. A serious accident may occur when an unexpected situation occurs during installation operation.

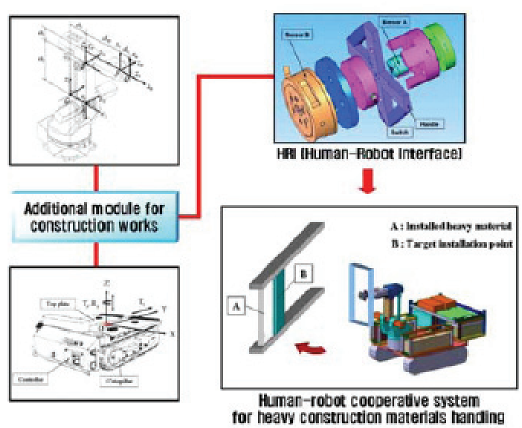

Figure 2 MFR System for Construction Work

Figure 3 Simulation of Installing Construction Materials

In this study, the upgraded additional module is introduced: the intuitive OCU for a remote-controlled MFR system.

3. UPGRADED ADDITIONAL MODULE: INTUITIVE OCU

3.1 Hardware

The hardware of the upgraded additional module is partitioned into an intuitive OCU, an end-effector, a CCD camera. A 6DOF manipulator and a 3DOF mobile platform are controlled by the intuitive OCU. The construction robot control makes use of a remote-controlled system. This control method is important because the operator does not get accurate information about work and situations, in order to respond instantly during changing work environments in real time. To address these problems, the concept of a force-reflecting joystick and a vision system is introduced, which transmit work information to the operator. The operator controls the manipulator using the joystick of the intuitive OCU, as shown in Figure 4, to perform theinstallation. There are 8 channels for work performance on the force-reflecting joystick and a lever rotates to the front, back, left, and right sides. It consists of a lever installed gear box, a motor to execute the force-reflection, a potentiometer to measure the rotating angle of the lever, and a control circuit device.

Figure 5 shows the F/T sensor for measuring contact force. If the construction material contacts to the environment (experiment system), information concerning the contact force is transmitted to the reflecting joystick through a wireless module. A motor rotates according to the signal of the transmitted information that is transmitted to the installed control circuit device at the lever in the force-reflecting joystick. Therefore, the operator will know the contact situation of a construction material through the reaction force by the rotating lever. The construction material can be installed safely by grasping the work situation of the robot through a CCD camera on the manipulator.

The end-effector of a construction robot varies according to the properties of the construction materials. Since this paper aims at installing construction materials with relatively smooth surfaces, a vacuum suction device is used as the end-effector. If the vacuum suction device that is located between the HRI device and the construction material makes a vacuum contact with the use of a motor, the construction material and end-effector are strongly attached to each other. Additional safety devices for the operator and an alarm device for alerting neighboring operators of the robot operation are necessary, while considering environmental conditions and characteristics of construction sites. Also necessary are control devices and interfaces that implement software and the separate power supply systems to operate the robot.

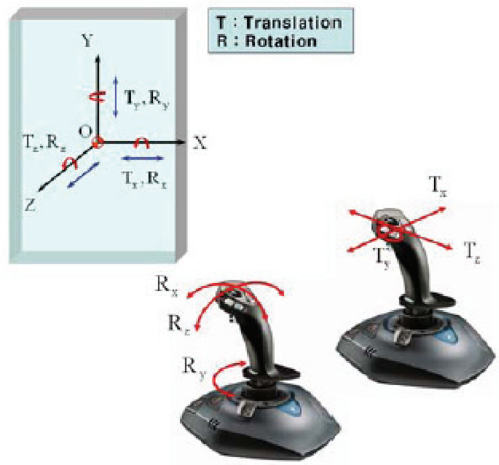

Figure 4 Force-Reflection Joystick (Logitech Co.)

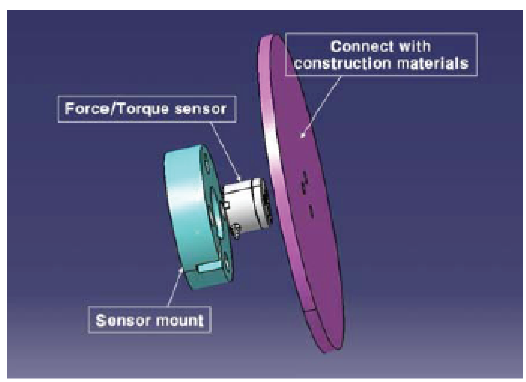

Figure 5 F/T Sensor for Measuring Contact Force

3.2 Software

The software of the upgraded additional module refers to a control algorithm which is necessary for installing construction material with the intuitive OCU. In this paper, 'free space motion control' and 'constrained motion control' are proposed as methods to control a MFR with the intuitive OCU. The free motion control is used to carry construction materials to a desired position. The constrained motion control is used to install construction materials and precisely move them when the end-effector of the manipulator contacts the environment. Bilateral communication and an active compliance control are proposed for the constrained motion control. Bilateral communication can occur for two situations simultaneously. Initially, the operator transmits command signals to the force reflecting joystick. Then, the input signals have cartesian-space coordinate system attributes. These are different attributes than the joint-space coordinate system for the driving actuators of the manipulator. Simultaneously, reaction forces are transmitted to the operator when the end-effector of the manipulator contacts the environment. Figure 6 shows the flowchart for the bilateral communication. The active compliance control algorithm is executed based on the operator's commands (forces), which are input by the force-reflecting joystick of the intuitive OCU, and information on the reaction forces obtained by the manipulator of the MFR when it contacts the environment. It can protect the MFR system and the construction material by regulating the system compliance when contact with the environment occurs. If the reaction forces exceed the elastic limit of the construction material, then a manipulator moves the position, which reduces the reaction forces. At the same time, the operator is able to intuitively control through the reaction forces when the manipulator of the MFR makes contact with the environment at a long distance. Figure 7 and Table 1 show the signal flow of the control system.

4. EXPERIMENT

An experiment for installing construction material was implemented, in order to evaluate the performance of the proposed intuitive OCU. Initially, construction material on the ground is gripped to the MFR with a vacuum suction device, and the MFR is moved to an installation position by command signal of the intuitive OCU. The operator can handle the construction materials through a CCD camera that is attached to the body of the manipulator as shown in Figure 8. The construction material carried to the vicinity of an installation position is installed through interaction with experiment system. That is, compliance occurs upon contact, so that the press pit for the construction material and the MFR system is completed safely. Furthermore, at this time, the reaction force is transmitted to the operator and it provides an effective operator command. In this experiment, the weight of construction material was limited to 60[N], which considers the specifications of the manipulator and the manufactured models of a curtain wall that is a type of huge construction material.

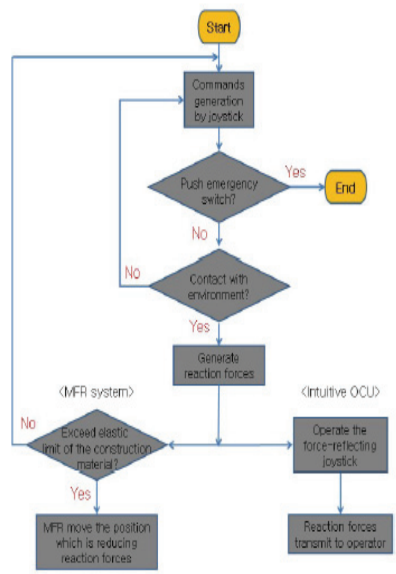

Figure 6 Flowchart for Bilateral Communication

Table 1 Signal Description of Figure 7

Signals	Description
A	Command signals (cartesian-coordinate system)
B	Digital signals
C,H	Wireless signals
D	Control signals (current)
E	Contact forces
F	Reaction forces
G	Sensor signals (analog signals)
I	Reaction force signals
J	Control signals (current)
K	Reaction forces

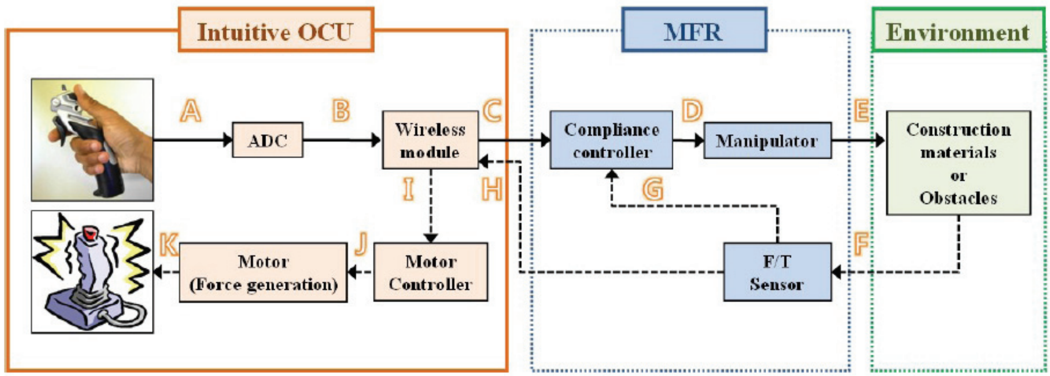

Figure 7 Signal Flow of Control System

Figure 8 Experiment System

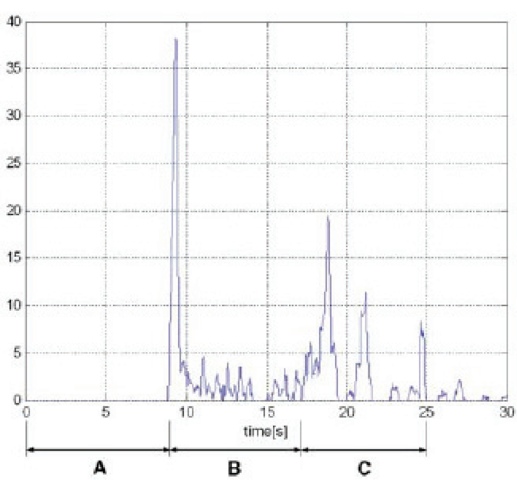

Figure 9 Experiment Result (Contact Force)

$$F(\text{contact force}) = \int_0^T \frac{\sqrt{F_x^{\,2} + F_y^{\,2} + F_z^{\,2}}}{T(\text{time})} dt$$

Figure 9 shows the contact force from the simulation for installing construction material using an experimental system. A section from 1 second to 8 seconds is a free-space motion, in which the construction material is carried to the installation position. A section from 'A' to 'B' is a step to control the compliance when contact with the environment occurs. After 17 seconds, a construction material controlling the compliance is carried horizontally and vertically to be inserted between the supporting board. This signal is transmitted to the motor controller in the intuitive OCU through the wireless module.

5. CONCLUSION

The proposed intuitive OCU combines force reflection with a vision system. An operator receives transmitted reaction forces from a force reflecting joystick with bilateral communication. The active compliance control algorithm is executed that is based on an operator's commands (forces), which are input by the force-reflecting joystick of the intuitive OCU and information on the reaction forces obtained by the manipulator of the MFR when it contacts the environment. It can protect the MFR system and the construction material by regulating of system compliance when contact with the environment occurs. This algorithm is verified by the results of the experiment for installing the construction material.

The intuitive OCU is expected to conduct safer and more accurate work at construction sites as well as hazardous environments that a human will not likely approach. In the near future, an autonomous MFR system will be developed that can avoid obstacles and generate a path automatically when moving from point-to-point in construction sites.

6. ACKNOWLEDGMENT

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