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HUMAN ROBOT COOPERATIVE CONTROL AND TASK PLANNING FOR A GLASS CEILING INSTALLATION ROBOT

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ABSTRACT

Building materials and components are much larger and heavier than general industrial materials. A glass panel is a type of building material used for interior finishing. The demand for larger glass panels has increased along with the number of high-rise buildings and an increased interest in interior design. The objective of this study is to introduce robotic technology for installing a glass panel on a high ceiling. After job definition, we established a design concept for the proposed robot. Finally, we described the detailed design of the robot in a past symposium. In this paper, the control algorithm relating the human-robot cooperation to which the hardware of the integrated system is to be applied, is presented. Also, the task planning for robotized construction is applied.

KEYWORDS

Glass ceiling, Installation robot, Human Robot Cooperative control, Task planning

1. INTRODUCTION

Recent research has found that a lack of skilled manpower in the Korean construction industry is rapidly becoming a serious problem. It is estimated that there will be a shortage of about 423,000 skilled laborers by 2010. This problem of a shrinking workforce, coupled with an aging society, leads to higher wages, a drop in construction quality, project delays, increased costs and the increased likelihood of accidents occurring at construction sites. One of the solutions suggested to solve these problems is robotization or automatic installation [1], [2].

Operations involving automation systems and robots are widely found at construction sites. Since the late 1980s, construction robots have helped operators perform hazardous, tedious, and health-endangering tasks in heavy material handling. Iwamoto et al. stated a similar problem that reduces the need for a labor force and provides improved productivity and safety [3]. Masatoshi et al. proposed the automated building interior finishing system, and a suitable structural work method is described [4]. 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 [5].

Building materials and components are much larger and heavier than many other industrial materials. Buildings are made of many kinds of materials and each material may be a different shape. A glass panel is one type of building material used for interior finishing. The demand for larger glass panels has been increasing along with the number of high-rise buildings and the increased interest in interior design.

In construction, the product is custom-made and robots must be reprogrammed to operate under each given condition [6]. Consequently, 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. However, during operation of a remote-controlled construction robot, problems arise due to operators receiving limited accurate information; the contact force applied by the robot can damage building materials such as pit from the contact force, thus reducing the ability to respond to the constantly changing operational environments. A human-robot cooperative method, in which an operator can construct materials intuitively, is suggested as a solution.

The objective of this study is to introduce robotic technology for installing a glass panel on a high ceiling. This robot is receiving special attention because of the difficulties of lifting the glass to high installation positions and handling the fragile building material. In order to address these conditions, the form of a glass ceiling installation robot is different from other construction robots. The prototype of human-robot cooperative system presented in this study, combines a mobile platform and a manipulator to compose its basic system. Also, the hardware and software are composed of a HRI (Human Robot Interface) device and combined with the basic system. The design for the suggested robot was explained in a past symposium [7]. In this paper, the control algorithm relating the human-robot cooperation, to which the hardware of the integrated system is to be applied, is explained. Also, the task planning for robotized construction is applied.

2. CONCEPT DESIGN

2.1. Job Definition

Existing glass ceiling installation work, which is complicated and hazardous, relies on scaffolding (or aerial lift) and human labor. This process exposes operators to falling accidents or vehicle rollovers. In addition, inappropriate working posture is a major element that increases the frequency of accidents by causing various musculo-skeletal disorders and decreasing concentration [8]. That is to say, it becomes a direct cause of decreasing productivity and safety in construction.

Figure 1 shows the construction site and glass ceiling installation position (soffit for building) related to this study. The installation position of the glass ceiling is 15m above the ground. The glass ceiling measures 3000mm × 1500mm and weighs approx. 160kg. The construction method is Module T&H-bar, which represents the 'Lay-in' to place the glass ceiling on ceiling frames.

Figure 1. Construction site and soffit for building

2.2. Functional Requirements

According to the job definition, it is deduced that the functional requirements for implementing a ceiling class installation robot are as follows:

- This robot must be able to lift heavy glass ceiling, an operator, and the installation equipment. It requires engines, batteries, or motors to lift them.
- This robot must be able to handle heavy and fragile glass ceiling. It requires sophisticated force and position control including human-robot cooperative control. That is to say, the operator must be able to perceive external information that is received by the robot.
- This robot must be devised to help operators, not to replace them. This requires a smart HRI device to interact with operators and robots. The robot must share the workspace with an operator.
- This robot must be able to reflect the technical operator's skills that are required to obtain homogeneous construction quality. Thus, the robot must follow the operator's intentions in various environments at unstructured construction sites.
- This robot must belong in the task planning. This is required to prevent operator accidents and help operators increase productivity, by reducing the recovery time from accidents and increasing the operator's duty time.

3. ROBOT HARDWARE

According to analysis of the functional requirements, a concept design was generated as shown in Table 1. Figure 2 shows a schematic of a glass ceiling installation robot that was developed by analyzing the concept design. The hardware of the proposed system is classified into two parts: the basic system and a HRI device. An aerial lift and an industrial multi-DOF manipulator are suggested for use in the basic system. The HRI device is involved with installing glass ceiling by correlating the operator with a manipulator. This device plays a role in delivering the operator's intentions to the robot controller. It is positioned between the flange of the multi-DOF manipulator and the vacuum suction device, as shown in Figure 3, while it is composed of two 6-axis F/T sensors.

Table 1 Concept design of a glass ceiling installation robot

Functions	Descriptions
Aerial work	Height of the workplace of 15m
Allowable weight	Laborer: approx. 70kg Glass ceiling: approx.160kg
Construction method	Lay-in method inserting the glass ceiling into frame
Installation Gripper	Vacuum Pad type handler
Control strategy; Human-Robot Cooperation	Intuitive manipulation Power assistance Force reflection

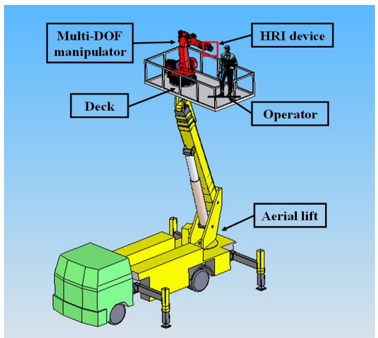

Figure 2. Schematic of a glass ceiling installion robot

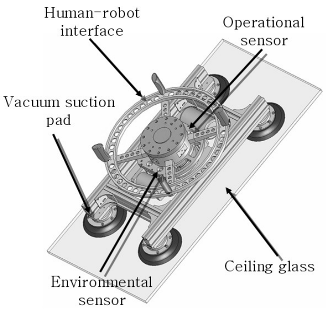

Figure 3. Vacuum suction device and the HRI device

4. HUMAN ROBOT COOPERATIVE CONTROL

We categorized the glass ceiling installation work through the human-robot cooperation-work into the environment-contacting case and the non-environment-contacting case. From the viewpoint of operational characteristics, the former case can be thought as a press-fit operation under interactions with a glass frame, which requires relatively higher stability. On the contrary, the latter case can be considered as the operation of moving a glass ceiling promptly to an installation site, which requires relatively higher mobility.

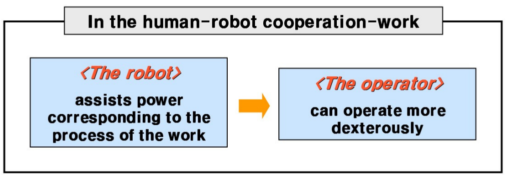

Figure 4. Concept of the HRC work

Figure 4 shows the concept of the HRC (Human-Robot Cooperation) work. When an operator supplies an external force containing an operational command on a handler of the HRI device, it is converted into a control signal to operate the robot with an operational sensor. If the robot comes into contact with the ceiling

frame, the information about the contact force/torque is transmitted to the robot controller through an environmental sensor. It is important to note that an external force/torque transmitted through an environmental sensor or the operational sensor occurs separately from each other. In the case of inserting a glass ceiling into the correct position or doing press pits, contact force (F_e) occurs from the contact surface. Although contact force is generated upon contacting the frame, for this paper, the glass is installed through press pits by generating compliance within the elastic range of the frame. Consequently, the generated contact force was presented as the sum of the maximum force (F_{th}) that could be exerted on materials within the elastic range and the contact force ($F_e^{'}$) input from a sensor in excess of the force.

The cooperation-based control algorithm for the non-environment-contacting case and the environment-contacting case, as mentioned above, is shown in Figure 5. Two cases depend on the presence of contact force generated by contact with the environment; position control is performed through an operator's sensory organs and central nervous system in free space. In the case of contact, a comparison is made between the extent of F_{th} and F_e to control indirect forces, which in turn controls the robot's position. When an operator judges that the position (X) to which a robot carries materials fails to agree with the position (X_d) to which he or she wants to carry them, his or her force is transmitted to the operational sensor. The deviation between the target position (X_d) and the present position (X) decreases as feedback is received through the encoder of a position controller, resulting in 0.

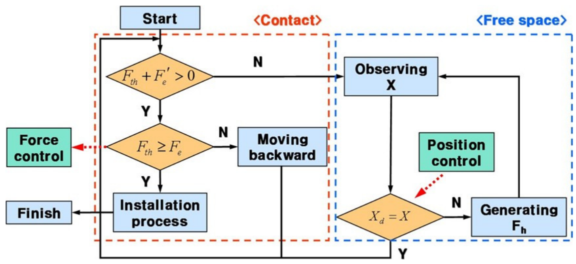

Figure 5. The cooperation-based control algorithm

5. TASK PLANNING & FIELD TEST

5.1. Task Planning

The construction procedure of installing glass ceiling with the robot can be classified into two processes: the first one is to deploy an aerial lift on which a deck (aerial platform) is mounted and put the deck in the desired position with telescopic booms. The second one is to follow the optimal path making a laborer install the glass ceiling with assistance by the robotic system through the human-robot interface.

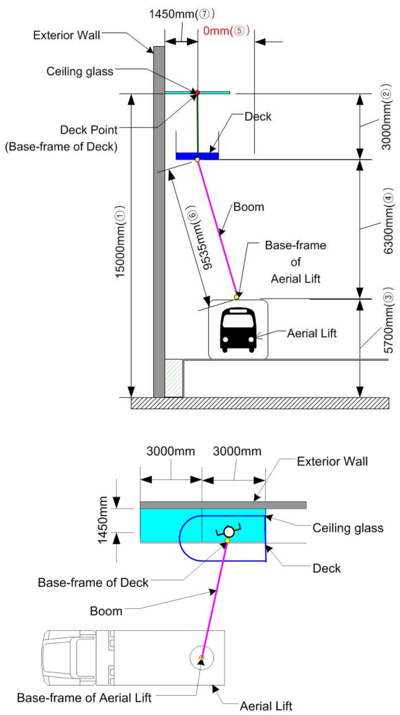

Figure 6. The deployment of the aerial lift and deck

Once the workspace to be deployed is guaranteed, the kinematical method can provide the appropriate position of the deck as shown in Figure 6. After the deployment of the deck, the task planning only relies on the relation between the end-effector and the frame in which the glass ceiling is laid. As is widely known in other applications, a computer simulation can solve this problem easily. Results from the simulation will give the optimal path in the form of graphs as shown in Figure 7, which is not the only solution, but can be used as a reference to project the moving trajectory.

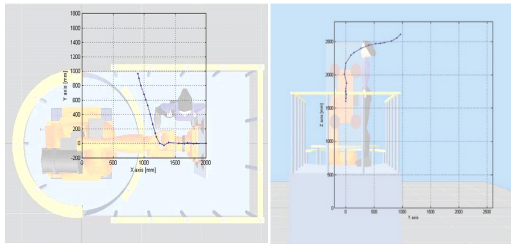

Figure 7. The trajectory resulting from simulation

5.2. Field Test

The proposed robot is developed to construct the soffit, an exterior as shown in Figure 1. From the task planning, the proposed construction process can be described as below:

- The deployment of an aerial lift on which the proposed robotic system is mounted
- Loading the glass ceiling on the deck
- Carry the glass near the frame in which the glass is laid
- Install the glass and finish the work

Before lifting the deck, one piece of glass is loaded on the deck. Then, according to the deployment plan, the robot approaches the workplace as shown in Figure 8. The glass is then supported by outriggers and the installation begins according to the process shown in Figure 9. The procedure of installation cannot be defined systematically because it depends on the skill of workers and the construction environment which is unconstrained or not repetitive.

Figure 8. Loading & lifting of a glass ceiling

Figure 9. Installing & finishing of a glass ceiling

6. CONCLUSION & FUTURE WORK

This research is a program of construction automation and robotization aimed for heavy material handling and installation. The glass ceiling installation robot presented in this study combines an aerial lift and a multi-DOF manipulator. One of the advantages of the proposed robot is the glass ceiling handling by human-robot cooperation. Included in this cooperation is the HRI device and the vacuum suction device combined with the multi-DOF manipulator. Also, considering parallel force and position control including human-robot cooperative control is made to increase the effectiveness. A task planning and field test using the robot is applied on a construction site. Table 2 shows the results of the field test.

Table 2. Results of field test

Parameters	Descriptions
Working time	Avg. 26min/piece(including finishing)
Labor intensity	Generally low labor intensity
Safety	Reduction in danger and accidents
Laborer	4(deck:3, aerial lift:1)

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REFERENCE

[1] Roozbeh K. (1985) Advanced robotics in civil engineering and construction, *International Conference on Advanced Robotics (ICRA '85)*, St. Louis, Missouri

[2] Warszawski, A. (1985) Economic implications of robotics in building, *Building and Environment*, 20(2), pp. 73–81.

[3] T. Fukuda, Y. Fujisawa, et al. (1991) A new robotic manipulator in construction based on man-robot cooperation work, *Proc. of the 8th International Symposium on Automation and Robotics in Construction*, pp. 239~244

[4] Masatoshi H. et al. (1996) Development of interior finishing unit assembly system with robot: WASCOR IV research project report, *Automation in Construction*, 5(1), pp. 31–38

[5] Seungyeol Lee et al. (2006) Multidegree-of-freedom manipulator for curtain-wall installation, *Journal of Field Robotics*, 23(5), pp. 347–360

[6] Cousineau L., Miura N. (1998) Construction robots; the search for new building technology in Japan, *ASCE press*

[7] Seungyeol Lee et al. (2007) Design of a ceiling glass installation robot, *Proceedings of the 24th International Symposium on Automation and Robotics in Construction*, Kochi, India, September 19–21, pp. 247–252.

[8] Kee, D. Y. (2002) A method for analytically generating three-dimensional isocomfort workspace based on perceived discomfort, *Applied ergonomics*, 23, pp. 51–62