A human-robot cooperative system helps out with glass panels in construction

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Abstract: Building materials and components are much larger and heavier than many industrial materials. Glass panel is a type of building material for interior finishing. The demand for larger glass panel has increased along with the number of high-rise buildings and an increased interest in interior design. The objective of the study is to introduce robotic technology for installing glass panel on construction site. Robotically installed glass panel is receiving special attention because of the difficulties in moving to high installation positions and handling fragile building materials. The human-robot cooperative system can cope with various and untypical constructing environment through the real-time interacting with a human, robot and constructing environment simultaneously. Therefore, a human can feel and response the force reflected from robot end effecter acting with working environment. After analyzing a target project, we establish a design concept for a proposed system. Finally, we describe the prototype of the system.

Keywords: Human-Robot Cooperative System, Glass panel, HRI(Human Robot Interface)

I. 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]. Isao et al. discussed the appropriateness of the automation technology for installation of a curtain wall [4]. Masatoshi et al. proposed the automated building interior finishing system, and a suitable structural work method is described [5]. 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 [6].

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. Glass panel is one type of building material for interior finishing. The demand for larger glass panel has been increasing along with the number of high-rise buildings and the increased interest in interior design. The objective of this study is to introduce robotic technology for installing glass panel on construction site. Glass panel installation robots are receiving special attention because of the difficulties of transporting the glass to high installation positions and handling the fragile building material. In order to address these conditions, the form of a glass panel installation robot is different from other construction robots.

In construction, the product is custom-made and robots must be reprogrammed to operate in each given condition [7]. 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 when it carries out press pits, 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 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 were composed of HRI device and combined with the basic system. The suggested system can execute particular operations in various areas such as construction, national defense and rescue by changing the HRI device.

II. CONCEPT DESIGN

1. Analysis of Target Project

The existing glass panel installation process, 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 panel installation position related to this study. The building size is 32m × 22m and the installation position of the ceiling glass is 7.9m above the ground. Glass panel used for installation is classified into two categories. The first category is glass panel that has 3000mm × 1500mm dimensions and is 120kg. The second category is ceiling glass that has 1500mm × 1500mm dimensions and is 80kg. This paper introduces the 'Module T&H-bar' installation method, which represents the 'Lay-in' to place the glass panel on frames. According to analysis of the target project, it is deduced the functional requirements for implementing a glass panel installation system.

Fig.1. Construction site and installation position

2. Concept Design

The development methods for construction robots can be classified into two categories. The first category involves developing entirely new robots that can achieve requested work. The second category involves new robots implementing existing systems. The first method is beneficial in optimizing specifically requested work. However, the cost and time required by this method are the major drawbacks to developing new robots. The second method is difficult to optimize for target projects, but it can achieve efficiency with limited cost and time requirements. In this study, the second method is introduced to develop the suggested robot.

We categorized the glass panel installation work through the human-robot cooperation-work into the environment-contacting case and the non-environment-contacting case. From the viewpoint of operational

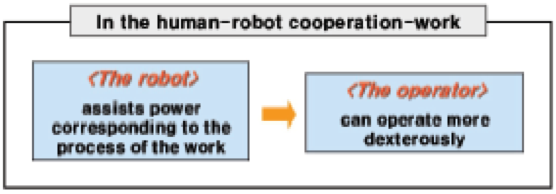


Fig. 2 Concept of the human-robot cooperation-work

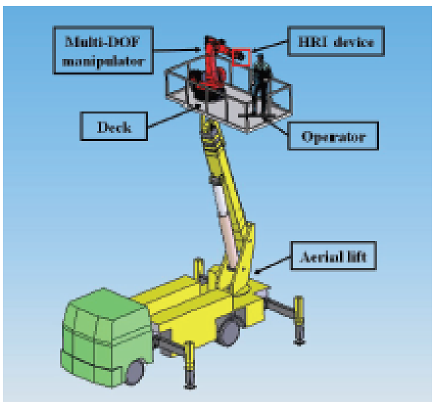


Fig. 3 Schematic of the glass panel installation system

characteristics, the former case can be thought as the press fit operation under interactions with glass frame, which requires relatively higher stability. On the contrary, the latter case can be considered as the operation of moving curtain walls promptly to an installation site, which requires relatively higher mobility. Fig. 2 shows concept of the human-robot cooperative system.

According to analysis of the functional requirements, a concept design was generated, which will influence the suggested system. Figure 3 shows a schematic of the glass panel installation system that was determined by analyzing the concept design. The hardware of the proposed system is classified into two parts: basic system and HRI device. An aerial lift and an industrial multi-DOF manipulator are suggested for use in the basic system.

III. BASIC SYSTEM

The basic system is classified into two parts, in consideration of the workspace and mobility: an aerial lift and an industrial multi-DOF manipulator. However, it is possible to change the elements of the basic system according to load specifications.

1. Aerial Lift

Aerial lifts are designed for enabling altitude work. In this study, the aerial lift raises the manipulator, glass panel and an operator up to 7.9m. In selecting a suitable aerial lift, diverse aspects were considered including mobility, reachable distance, and payload. The aerial lift must have adjustable movement within a constantly changing work environment. Therefore, considering mobility, a wheel type of aerial lift was selected, which is mounted on the truck with a telescopic boom. Considering the reachable distance and payload, it is necessary to expand the selection criteria to include not only specific properties but also safety concerns. Figure 4 shows the selected an aerial lift that can lift payload of 2000kg.

Fig. 4 An aerial lift

2. Multi-DOF manipulator

A multi-DOF manipulator is needed to install heavy glass panel, thereby replacing a large amount of human labor, by correlating the operator and manipulator. The manipulator is chosen to help the operators, not to replace them. The manipulator has to be chosen according to the work space and payload. The payload and the weight of any additional devices (vacuum suction device, HRI device) required for installation must be considered. Figure 7 shows the selected model (KUKA Industrial Robots). In order to control the motion of the manipulator, kinematic and dynamic analysis is required. As operator's safety is influenced by these types of motion, while any singularities in the hardware should be considered carefully.

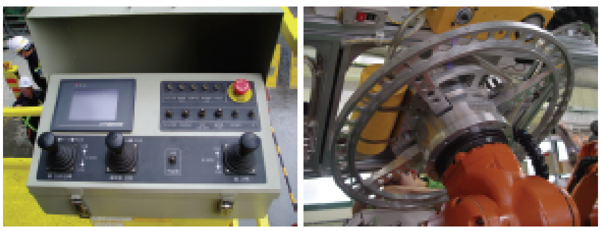
Fig. 5 A multi-DOF manipulator

IV. HUMAN ROBOT INTERFACE

Hardware necessary to install glass panels through human-robot cooperation can be largely divided into three groups as follows:

1) Human robot interface(HRI)s to control motion
2) End-effector to fix glass panels into the system
3) Other units necessary for construction work

First, the HRIs need to be able to implement DOF for an aerial lift and a multi-DOF manipulator. HRIs to control an aerial lift controller and a multi-DOF manipulator are shown in Figure 6. Concept of the HRI to control a multi-DOF manipulator is as below. If an



(a) Aerial lift (b) Multi-DOF manipulator

Fig. 6 A human robot interface(HRI)

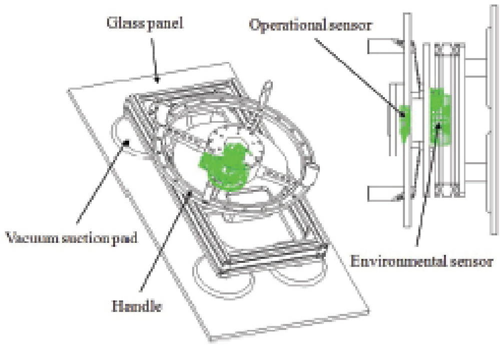


Fig. 7 HRI and vacuum suction pad

operator puts external force containing an operation command on a handle of the HRI, it is converted into a control signal to operate the manipulator with operational sensor(6 DOF force/torque sensor; ATI Industrial Automation, Inc.). Here, if the manipulator comes in contact with an external object, information on the contact force is transmitted to the manipulator controller through environmental sensor(6 DOF force/torque sensor). It is important to note that external force transmitted through environmental sensor and that transmitted to operational sensor should operate separately from each other.

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, such as glass panels, a vacuum suction pad is used as the end-effector.

Lastly, an outrigger to prevent a robot from tumbling, additional safety devices for the operator, and an alarm device to alert neighboring operators of robot operation are necessary, with consideration for the operation environments and characteristics of construction sites.

Figure 8 shows the prototype of a human robot cooperative system to install a glass panel. In this figure, the basic system consists of an aerial lift and a multi-DOF manipulator; the portion that excludes glass panel is an additional module(HRI, vacuum suction pad etc.) for construction works.

Fig. 8 Prototype of a human robot cooperative system

V. CONCLUSION

The prototype of human-robot cooperative system presented in this study combines an aerial lift and a multi-DOF manipulator. One of the advantages of the proposed robot is the glass panel handling by human-robot cooperation. Included in this cooperation are the HRI device and the vacuum suction pad combined with the multi-DOF manipulator. After fabricating each part of the robot system, integration is executed.

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