PROPOSAL OF INSTALLATION METHOD OF HEAVY DUTY GLASS USING INTUITIVE MANIPULATION DEVICE

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ABSTRACT: Glass is widely used as finishing material in order to allow good appearance from building inside and outside. And the trend of construction material and component is toward larger and heavier. So, safely to install this heavy duty and fragile glass, we proposed new methodology for glass installation. First we inquired all kind of glass installation robot widely. And we classified these robots, analyzed installation methods and compared to construction worker. Second we proposed new methodology which had similar to installation method of construction worker. Third we made an experiment system for performance evaluation. Lastly we confirmed that the glass installation work of proposed method is more efficiency than existing method through work time and force/torque interference. Also we confirmed that work time of installation work using proposed method is similar to that of construction worker. This method is to be the system combined with operator's control ability and robot's power. And, through this method, it is expected that glass installation work is to be more efficiency and safety.

Keywords: *Human-Robot Cooperation, Construction Robot, Intuitive Manipulation Device, Heavy Duty Glass, Virtual Axis*

1. INTRODUCTION

Until now, during the process of installing heavy materials on buildings inside and outside, handling materials has been mostly executed using by cranes or pulleys, whereas assembly and installation have been mostly done by construction workers. That is, under a changeable environment, the construction industry has a limit to wholly automatize or semi-automatize required capacities (such as accurate approach and alignment) on assembly and installation.[1] However these simple, repeated processes have not been automatized until now and the development of automated system or semi-automated system based on human-robot cooperation has been attempted to aid this situation.[2]

Gonzalez designed a power assistance device for the safety of the operator while installing plaster panels on construction sites. [3] Yu et al. developed a curtain wall installation robot for the safety of the operator and to increase work efficiency in unstructured construction sites.[4] KAJIMA Corp. developed 'Mighty Hand' for handling concrete and glass materials.[5] This corporation also developed a multi-jointed handling robot to install heavy materials on both inside and outside of buildings. Likewise, to install construction materials on ceiling of buildings, an interior finishing robot was developed by Shimizu Corp.. Lee et al. designed a ceiling glass installation robot to install heavy glass on buildings inside and out.[6] These heavy material handling robots particularly showed a possibility improving the operator's safety, work efficiency, and protecting construction materials at the same time. Still, these existing robots only demonstrated optimal performance for limited target tasks. On a practical level, it is realistically difficult for these robots to be applied because of their complex systems, high-cost and difficulty in mass production. Exceptionally, OKTOPUS developed by MATERIALS HANDLING Corp. in Australia, Mobile Ergonomic Handler developed by Arlington Equipment Corp. in USA, Geko & Glass Robot Hire developed by GGR Corp. in UK, and Spider Crane developed by Peter Hird & Sons Ltd. in UK have been commercialized on construction sites.[7-10] But these robots have limited capacities and maneuver.

Considering all these robots, we reached a provisional conclusion; the robot manipulation device can serve as an alternative since it is not only portable, but also enables the operator to directly handle the materials. This paper presents several techniques to realize the concepts such as virtual axis coordinate and input force treatment to generate robot motion commands. Finally, we verified the feasibility of the proposed system through simple comparison experiments.

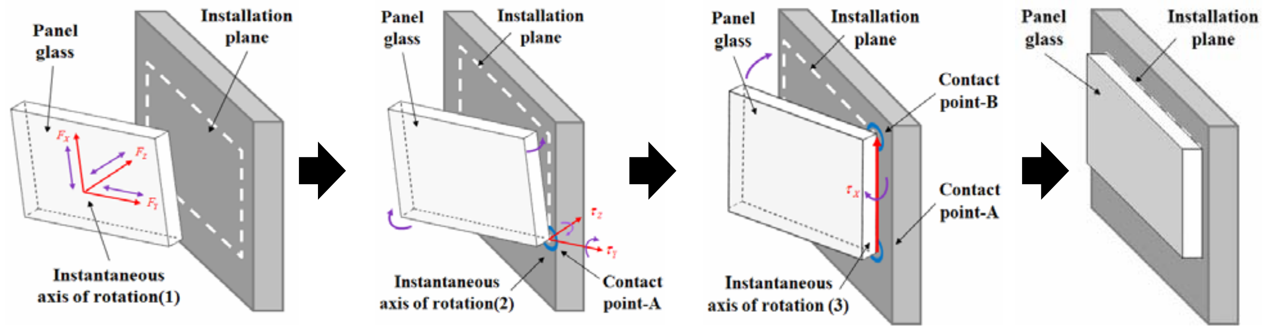
2. PROPOSAL OF A NEW METHOD

2.1 Analysis of Existing Methods

In order to analyze the existing methods, we need to classify the robots that were previously mentioned first. Depending on the input signal of robots, they are classified as robots driven in Joint space and Cartesian space. And based on the carrier, this paper classified as installation methods by operators and robots.

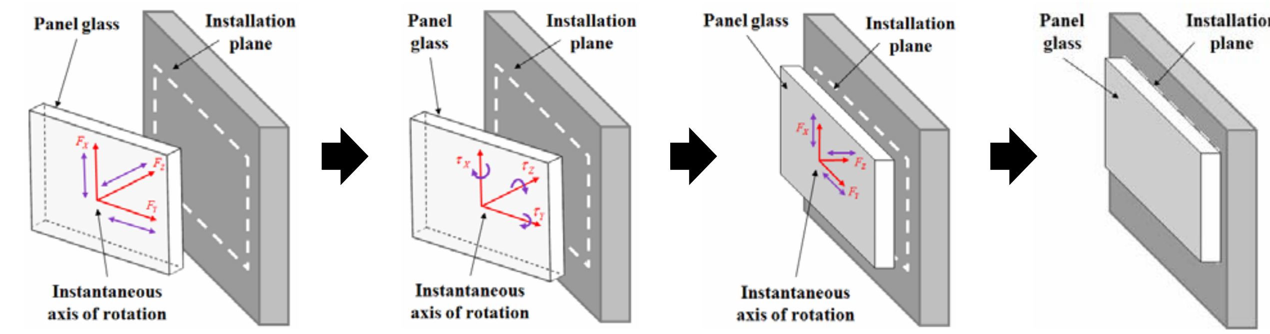
In case of construction worker, first, glass is transported near the contact point-A. At this time F_x, F_y, F_z are generated onto the instantaneous axis of rotation such as fig. 1 (a). Then T_y, and T_z are acted onto the instantaneous point of rotation (b). After that, the glass is rotated on contact point A which is put on glass. Next, T_x is generated onto the instantaneous axis of rotation (c). Then the glass is rotated on the rotational axis which is the vector derived from contact point A to contact point B. Finally, the installation work is finished.

Fig. 2 presents installation method by robot driven in Joint space. First, glass is closely transported to the target location with linear large motion. At this time, F_x, F_y and



(a) Linear motion (b) Rotational motion-T_Z, T_Y (c) Rotational motion-T_X (d) Finish work

Fig. 1 Installation method by construction worker



(a) Linear motion-large motion (b) Rotational motion (c) Linear motion-little motion (d) Finish work

Fig. 2 Installation method by robot – driven in Joint space

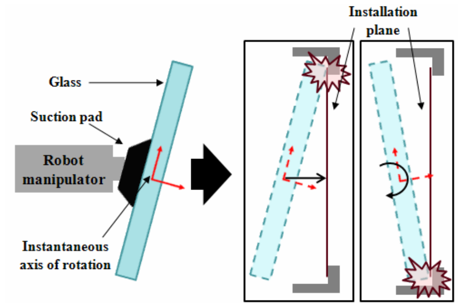


Fig. 3 Problem of installation method by robot (Joint space)

F_z are acted onto the instantaneous axis of rotation within the glass. Second, the glass is rotated near the intended install location. At this time, T_x, T_y and T_z are acted on the rotational axis for fitting the glass on installation plane on a parallel level. Third, the glass is fitted onto the destined place with linear little motion. After repeated motions described in Fig. 2 (b) and (c), the installation is finished. For installing a fragile material, an operator has to pay careful attention to the installation process. Also, a fixed instantaneous axis of rotation, such as Fig. 3, is the cause of increasing the repeated number of rotational and translational motions for the robot driven in Joint space. Therefore the installation work by robot driven in Joint space requires many more motions than work done by a construction worker. For these reasons, work efficiency of this method is lower than that of a construction worker.

To solve this problem, authors developed a ceiling glass installation robot, which is driven in Cartesian space. Theoretically the installation method using a robot driven in Cartesian space is more efficient than method using a robot in Joint space. However, this method is not efficient because of the following issues. Fig. 4 displays a problem of installation method by using a robot driven in Cartesian

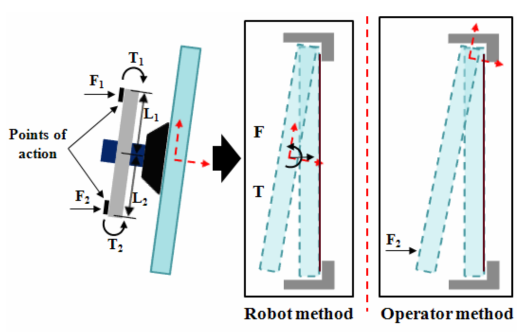


Fig. 4 Problem of glass installation by robot (Cartesian space)

space. This robot system uses a 6DOF F/T sensor for inputting the operator's force. In order to work more intuitively, the location of this sensor is set on the robot EEF. Then this sensor is inputted operator's force and torque. This robot system needs more than two points of action shown in fig. 4. With these points of action, the sensor not only receives the operator's torque but also torque generated between the operator's force and the moment arm. Therefore the operator's force and torque are not inputted to the sensor accurately and the robot is driven in unexpected motions. Also to install the glass in little motion, in case of robot method, simultaneously exact force and torque need to act on the glass. But in case of operator method, only linear force needs to act on the glass such as fig. 4. This problem of robot method is a cause of repeated motion. Consequently, these unexpected motions and repeated motion cause inefficiency.

Assuming that the installation method by an operator is ideal, the problems of each method by robots are as followings:

Table 1 The problems of each method

Installation method	Problem
By an operator	No problem (Ideal)
Using robots – driven in Joint space	Repeated motions
Using robots – driven in Cartesian space	Unexpected motions & Repeated motions

2.2 Methodology of the proposed method.

The proposed method in this paper is to carry the process out in the same way by the ideal operator's method. In the operator method, first, the instantaneous axis of rotation is located on the center of panel glass. Second, the instantaneous point of rotation is located on the edge of the glass. Third, the instantaneous axis of rotation is located on the contact line. But it is difficult for a robot to find these changeable instantaneous axes of rotation. Also the size and the location of the glass attached to the robots are subject to change. Therefore, in this paper, an operator decides the instantaneous axis of rotation. And the robot d-

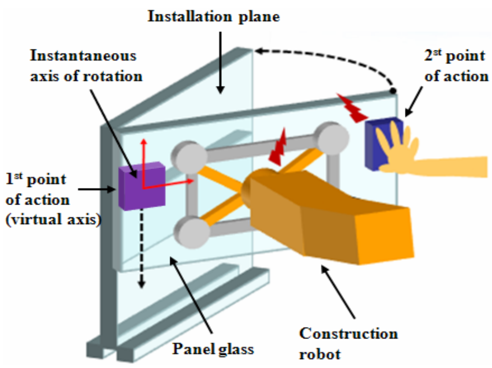


Fig. 5 Methodology of proposed method

-etects these axes. At this time, the points of action are located on these axes. There are 2 points of action specified in this paper. The first point (we assumed that this point to be the virtual axis) plays the role the instantaneous axis of rotation and decides the linear motion of the glass. The second point decides the rotational motion of the glass. The roles of these points are changeable by the operator. In other words, these points receive the operator's force and create the trajectory of robot EEF for handling the panel glass.

Fig. 5 presents the methodology of the proposed method it is explained as follows:

1. An operator decides on the linear and rotational motion of the glass while the robot handles the mass of the glass.
2. The proposed method carried out in the same method done by a construction worker.
3. The operator decides the instantaneous axis of rotation.
4. The first point defines the instantaneous axis of rotation and decides the linear motion of glass.
5. This paper assumes that the first point is a virtual axis.
6. The second point decides the rotational motion of the glass.
7. These points receive the operator's force and generate the trajectory of robot EEF.

3. OPERATION STRATEGY

3.1 Detecting Method of the Points of Action

In this paper, we assume that the instantaneous axis of rotation is within the intuitive manipulation device (IMD). In other words, the center axis of IMD corresponds to instantaneous axis of rotation. Therefore, detecting the poi-

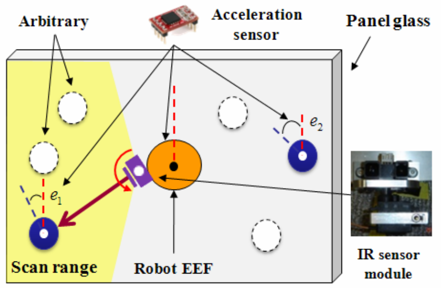


Fig. 6 Detecting method of the IMDs

-nts of action means that defining the position and the orientation of the IMD in respect to the robot EEF.

Due to various installation forms, working methods and irregular sizes of glass, the position and orientation of IMD put on the glass are not fixed. Additionally, the operator determines its position and orientation arbitrarily. Thus in this study, we used the IR sensor module and acceleration sensor to detect the position and orientation of the IMD. The IR sensor module is composed of an infrared sensor and a radio control motor. This sensor module is attached on the robot EEF. The IR sensor measures distance of the IMD's contour in respect to robot EEF while RC motor is rotating. Fig. 6 shows the detecting method of the IMDs.

3.2 Kinetic Relationship of Forces

In Cartesian space, the glass's position and orientation change, depends on the force and torque generated on the glass. And the operator's forces inputted from IMDs generate the trajectory of robot EEF. Therefore, to define this relationship, we considered 2 cases: when the virtual axis is at the robot EEF; when the virtual axis is at the IMD. If the virtual axis is placed at the robot EEF (Fig. 7), the force and torque are determined by the combination of the forces on each IMDs (left, right) as in equations (1) & (2).

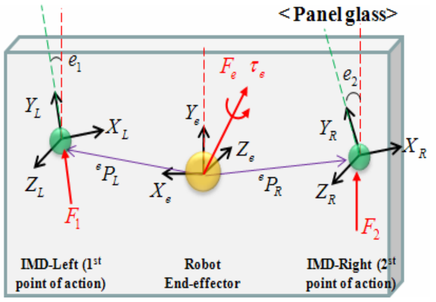


Fig. 7 Force and torque acted on robot

$$F_e = {}^e_L RF_1 + {}^e_R RF_2 \qquad (1)$$

$$\tau_e = {}^eP_L \times {}^e_L RF_1 + {}^eP_R \times {}^e_R RF_2 \qquad (2)$$

At this moment, Z_e, Z_L and Z_R are parallel and perpendicular to the panel glass because the IMDs and the robot EEF are put on a flat glass. The robot EEF's orientation, e_1 and e_2 are inputted from the acceleration sensors. 3-axes force vector acted on the left IMD is F_1 and force vector acted on the right IMD is F_2. ${}^eP_L$ is the position vector from the robot EEF to the left IMD and ${}^eP_R$ is the position vector from the robot EEF to the right IMD.

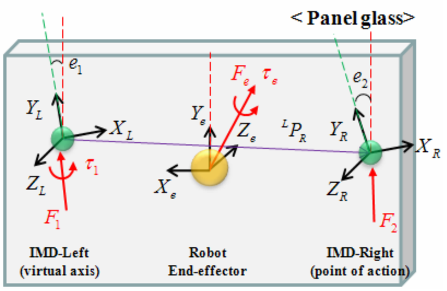


Fig. 8 Force and torque acted on virtual axis

Second, if the virtual axis is on the left IMD and point of action is on the right IMD (fig. 8), the worker's force on the virtual axis (IMD-left) determines the force of the robot EEF as in equation (3). And the force on the point of action determines the torque of the robot EEF. At this moment, the torque on the robot EEF is on the same as that on the virtual axis as in equation (4).

$$F_e = {}^e_L RF_1 \qquad (3)$$

$$\tau_e = \tau_1 = {}^LP_R \times {}^L_R RF_2 \qquad (4)$$

4. PERFORMANCE EVALUATION

To test the performance of the proposed method, we used a 6-DOF manipulator. And it is assumed that the installation location is a vertical wall with a spring-damper system.

In fig. 9, the work processes from (b) to (c) are large motion, part (d) is little motion and part (e) is work motion after the installation. And fig. 10 shows the operator's forces and torque acted on the IMDs and the robot EEF. In this case, the right IMD part (operator A) is an instantaneous axis of rotation and the left IMD part (operator B) is the point of action. In a large motion, the force summation vector (section B′) acted on the robot EEF is dependent on the force vector acted on the right IMD (section B). And the torque summation vector (section A′) acted on the robot EEF is dependent on the force vector acted on the left IMD (section A). Likewise, in the little motion, the torque summation vector is dependent on left IMD. Also, in the little motion, the small force summation vector (section C′) is generated. This force vector (section C′) is a compensation vector for error that occurred from the difference between the corner of the material (the actual instantaneous axis of rotation) and the center of the right IMD. Operator A decides this vector during little motion work. The total work time is about 62 second. This time is similar to method of operator.[11]

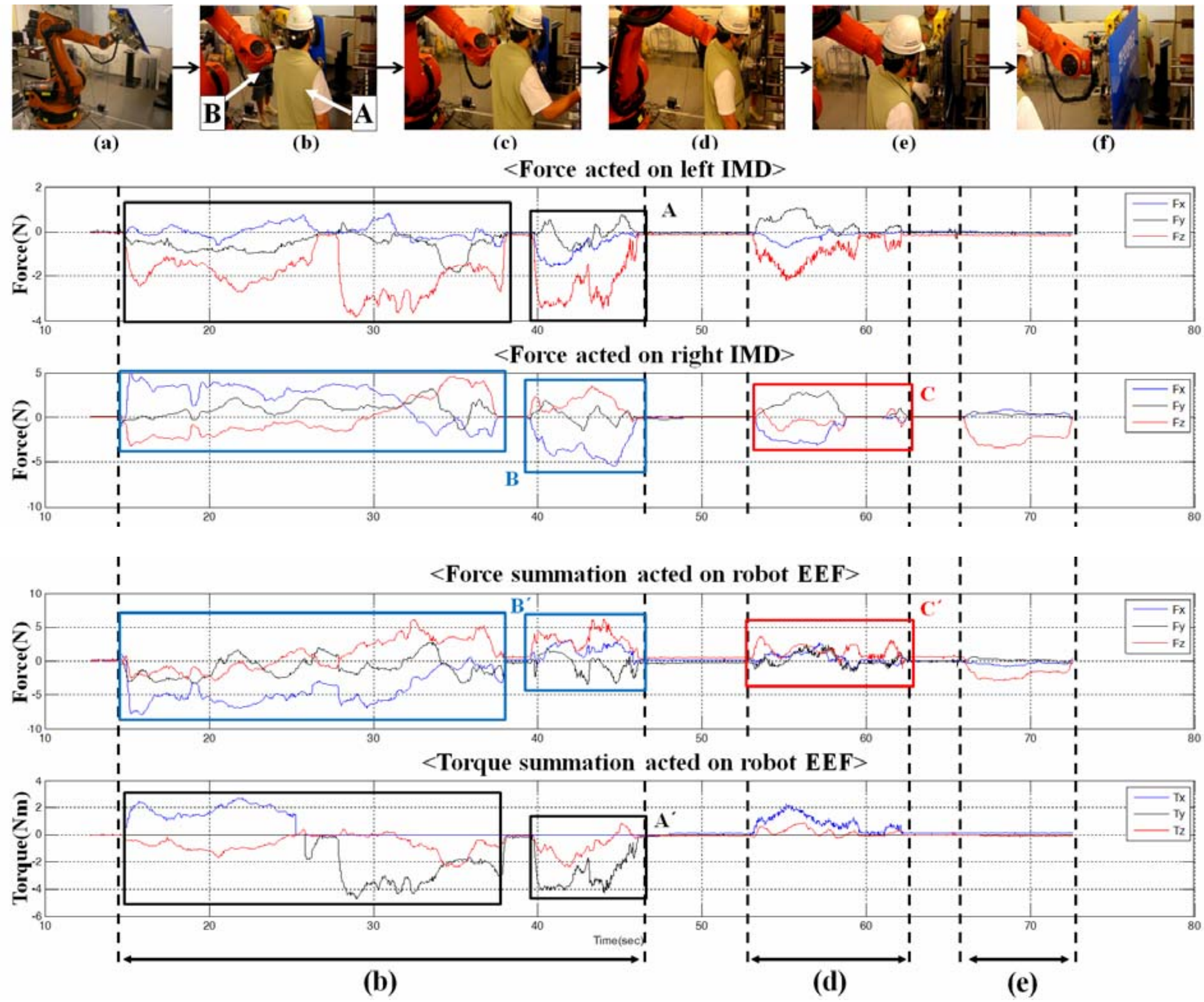


Fig. 9 Operator forces and torque acted on IMDs and robot EEF

5. CONCLUSION

To protect the glass and construction workers and increase the work efficiency, this paper proposed new methodology of installing the heavy duty glass. The method was similar to operator's method. This method presents how to detect the instantaneous axis of rotation and point of action of the glass. At this time, the position and orientation of these axes defined by operator changeably were corresponded to center axis of IMD. This paper defined that the instantaneous axis of rotation of IMD was to virtual axis. To detect the center axis of IMD, this paper used IR sensor module and acceleration sensor. And to understand the force relationship between action point and robot EEF, this paper analyzed kinetic relationship. To verify the proposed methodology, this paper performed a simple test using 6-DOF serial manipulator and compared to existing method. Resultantly, the proposed method was faster than existing method and similar to method of operator in time.

ACKNOWLEDGEMENT

This research was supported by the MKE(The Ministry of Knowledge Economy), Korea, under the 'Advanced Robot Manipulation Research Center' support program supervised by the NIPA" (NIPA-2010-C7000-1001-0 002), and a grant from Construction Technology Innovation Program(CTIP) funded by MLTM.

REFERENCE

[1] Carlos Balaguer and Mohamed Abderrahim, "Trends in Robotics and Automation in Construction", 2008, ISBN 978-953-7619-13-8, InTech

[2] T. Fukuda, Y. Fujisawa, K. Kosuge, F. Arai, E. Muro, H. Hoshino, T. Miyazaki, K. Outbo, K. Uehara, "Manipulator/Vehicle System for Man-Robot Cooperation", 1992 Proceeding of the 1992 IEEE International Conference on Robotics and Automation Nice

[3] P. Gonzalez de Santos, J. Estremera, E. Garcia, M. Armada, "Power assist device for installing plaster panels in construction", Automation in Construction, Vol 17, pp.459-466, 2008

[4] Seung-Nam Yu, Seung-Yel Lee, Chang-Soo Han, Kye-Young Lee and Sang-Heon Lee, "Development of the curtain wall installation robot: Performance and efficiency tests at a construction site", Autonomous Robots, pp.281-291, 2007

[5] "Mighty Hand", KAJIMA Co.,http://www. Kajima.co. jp/topics/perspect/vol_15_1/luke/water/index.html

[6] Seungyeol Lee, Myeongsu Gil, Kyeyoung Lee, Sangheon Lee and Changsoo Han, "Design of a Ceiling Glass Installation Robot", International Symposium on Automation and Robotics in Construction (ISARC 2007), pp.247-252, 2007

[7] OKTOPUS, www.materialshandling.com.au/, Australi a, Materials Handling Co.

[8] Mobile Ergonomic Handler, www.gotoartech.com, U. S.A, Arlington Equipment Co.

[9] Geko & Glass Robot Hire, www.ggrglass.co.uk, Engla nd, GGR Co.

[10] Spider Cranes, www.peter-hird.co.uk, England, Peter Hird & Sons Ltd.

[11] Myeong-Su Gil, Byung-Gab Ryu, ChengJie Li, Min-Sung Kang, Seung-Nam Yu and Chang-Soo Han, "Development and Performance Evaluation of Robot for the Installation of Heavy Ceiling Glass using the Human Robot Cooperation", 2009 KSME Autumn Annual Conference, pp.835-840, 2009