DESIGN OF TEACH PENDANT FOR ROBOT GLAZING SYSTEM

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DESIGN GUIDELINES OF A TEACH PENDANT FOR A GLAZING ROBOT

ABSTRACT

Currently, a new construction method using a robotic system is widely spreading in construction sites. This study is related to the design of glazing robot's teach pendant which can improve convenience of handling and hence improve the productivity through the efficient interaction between an operator and a robot while doing glazing works, e.g., curtain wall installing. The suitability of selection and arrangement of control switches was assessed according to mechanical motions of a glazing robot, and design guidelines for improving convenience and productivity were drawn up through questionnaires carried out by site operators. To verify the proposed design guidelines, working time comparison of the proposed teach pendant and the existing teach pendant was executed.

KEYWORDS

Teach pendant, Design guideline, Curtain wall, Glazing robot

INTRODUCTION

Buildings are made of many kinds of glasses and each glass may be a different shape. Building glasses and components are also much larger and heavier than many other industrial glasses. Moreover, the demand for curtain walls has been increasing according to high-rise buildings and increased interest in spectacles. Most of the current curtain wall installing processes, which are complicated and hazardous, rely on unsuitable construction equipment and human labor. These processes demand an intensive labor burden and create a high frequency of accidents (Lee et al., 2007). In addition, inappropriate working posture is a major element that increases the frequency of accidents by causing various musculo-skeletal disorders and decreasing concentration (Bernard, 1997; Kee, 2002; Kilbom, 1994; Westgaard and Aaras, 1984). That is to say, it becomes a direct cause of decreasing productivity and safety in construction.

In the construction industry, the use of 'automation systems and robots' has been proposed as one of the most obvious answers to improve safety, productivity, quality and the working environment (Poppy, 1994; Roozbeh, 1985; Skibniewski and Wooldridge, 1992; Warszawski, 1985). Cusack (1994) mentioned that by making use of such construction robots at construction sites, the incidence of accidents can be reduced by decreasing the number of unnecessary workers, time and cost of construction, and especially by performing dangerous work which otherwise would involve many workers.

Generally, a teach pendant of robotic systems used presently in the construction sites usually consists of industrial control switches. Moreover, most manual robot controllers are designed without enough technical information regarding the suitability of a control switch for various operations and convenience of handling by the operator. Also, studies about mutual correlations between convenience and improved productivity have not yet been carried out.

The aim of this study is to prepare design guidelines of a manual robot controller which can improve convenience of handling and hence improve the productivity through the efficient interaction between an operator and a robot while doing glazing works, e.g., curtain wall installing. The suitability of a control switch was assessed according to each mechanical motion, and design guidelines for improving convenience and productivity were drawn up through questionnaires carried out by site operators.

The overall study procedure is as follows. First, characteristics of mechanical motions when installing curtain walls are analyzed. At the same time, problems of existing manual robot controllers are noted through questionnaires. Then, assessment subjects and devices are defined to evaluate the suitability of a control switch and the correlation between convenience and productivity. Lastly, the correlation matrix (i.e., design guidelines) is drawn up through an analysis of the questionnaire results. A design concept for a glazing robot's teach pendant, suitable for operation, will be then derived from the perspective of productivity and convenience, by applying the design guidelines and other technical data drawn up to various robotized construction works.

ANALYSIS OF EXISTING MANUAL ROBOT CONTROLLER

Characteristics of Mechanical Motions

When designing the manual robot controller necessary for curtain walls installation, matching the actual robot motion and mechanical motion of the control switch should be considered. To express mechanical motions necessary for robots easily, a Cartesian coordinate system is applied with the origin at the center of the curtain wall and degree of freedom around the X, Y, and Z axes. To express the mechanical motions of the curtain wall moved by the robot, straight translation motion is expressed as 'T', and rotation motion is expressed as 'R' as shown in Figure 1. Also, x, y, z subscripts indicate the coordinate axis of the direction of motion.

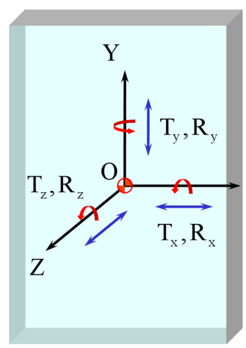

Figure 1 – Mechanical motions of a glass panel

Problems of Existing Manual Robot Controller

Some of the problems of the existing manual robot controller when in use were drawn up through interviews of site workers who use the controller and are as follows. The 7 factors derived through problem analysis prove that existing manual robot controllers do not consider the convenience of users and therefore they are unable to improve productivity and convenience.

a. The body of the manual robot controller does not consider mobility and convenience for users, and it is also not resistant to water or dust.
b. The joystick which controls the direction of mechanical motion is located on unsuitable position of the manual robot controller, thus causing malfunction of other control switches and aggravating fatigue of users who handle it.
c. Wired controllers which use cables may cause many problems at construction sites where there are many obstacles due to the special working environment, such as being caught in surrounding obstacles or the severing of cables by obstacles.
d. The size of the controller is larger than necessary for the purpose of protection against shock, and it becomes an inconvenience when the controller is held and operated with one hand.

e. The location and shape of the buttons are not user-friendly, and the buttons are located where they are not easily recognized for each direction of motion.
f. A separate monitoring device on the controller is necessary since the collection of altered work information is difficult when curtain walls are aligned and assembled at construction sites.
g. Safety devices (such as an emergency switch) for the safety of the system and switches of other accompanying devices cause inconvenience during operations.

ASSESSMENT

Subjects

Assessment of the suitability of a control switch and correlation between productivity and convenience was carried out through questionnaires and interviews of targeted on-site operators who currently deal with the controllers of various construction robots and equipment. The questionnaires were given in the Metropolitan area to 100 males above the age of 20 who had dealt with construction robots and equipment for at least 1 year and who live in the Seoul and Gyeonggi area in Korea. Most of the respondents were excavator or wheel loader drivers (42 people) and the others included drivers of various kinds of construction equipment (tower cranes, bulldozers, off-road trucks, etc.) (39 people). Also, developers and drivers of construction automation systems, including the curtain wall installation robots mentioned in this study, were surveyed as well (19 people).

Devices; Control Switches

The teach pendants of construction robots and equipment dealt with by respondents consist of various industrial control switches. The most commonly used control switch was selected as an assessment device among the controllers (Figure 2). The 4 items in the figure show only the functional part from a similar product to find out characteristic operations suited to various distinct mechanical motions.

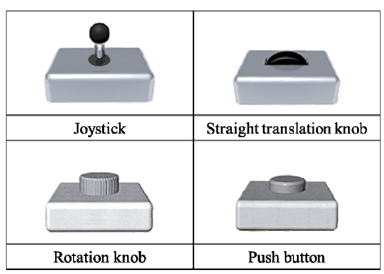

Figure 2 – Assessment device (i.e., Control Switches)

Questionnaire

Assessment data were obtained through questionnaire sheets drawn up during interviews. Firstly, assessment items are classified largely into 2 categories as follows.

a. Assessment of the suitability of control switches for different motion characteristics
b. Assessment of the correlation between productivity and convenience

The first assessment goal was to choose the most suitable control switch according to the different characteristics of motion (straight translation motion, circling motion, continuous motion, and frequent start/stop). The assessment was carried out after listing each item from the 4 kinds of control switches in Figure 2, in the appropriate order.

The second assessment is to find the correlation between productivity and convenience in handling from the perspective of the manual robot controller. Correlation between the assessment standard of productivity (efficiency, capability, functionality, safety and maintenance) and the assessment standard of ease in handling (consistency, compatibility, handling, distinguishment, suitability and aesthetic quality) were assessed into 5 grades (from 'unrelated' to 'highly related'), as shown in Figure 3. Table 1 shows both assessment standards and the definitions of productivity and convenience separately.

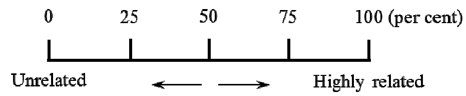

Figure 3 – Criteria of relationship

Table 1 – Assessment standards and definitions

Type	Assessment Standards	Definitions
Productivity	Efficiency	Efficiency of a machine, effectiveness of an operation
	Capability	Credibility of input regarding desired output, degree of sufficient resolving power
	Functionality	Ability to satisfy necessary functions within working environment and with special motions considered (in wired/wireless form suitable to the surroundings)
	Safety	System safety considering environmental factors (obstacles)
	Maintenance	Durability, resistance to dust, constant temperature and moisture
Convenience	Consistency	Consistent handling with similar components (indication device, control device) to existing similar controllers (familiar controlling)
	Compatibility	Compatibility of space, compatibility of movement, compatibility of techniques and control device with distinct operations in mind (prevents malfunctioning)
	Handling	Usability with human body measurements and work area in mind, immediate response and smooth handling of control device (bodily characteristics considered)
	Distinguishment	Easily distinguished because of arrangement and coloring of the control device (monitoring device)
	Suitability	Controller and controlling method suitable to purpose and the direction of motion considering the working environment (distinct working environment considered)
	Aesthetic quality	Aesthetic value (tactility, color, outer design, how to mount/carry)

RESULTS

Suitability of Control Switches

Assessment of the control switches' suitability for the 4 characteristic motions (straight translation motion, rotation motion, continuous motion and frequent start/stop) is shown in Figure 3. To begin, a joystick was selected as the most suitable control switch for straight translation motion and a circular knob for rotation motion. The push button switch was most suitable for frequent start/stop and also for continuous motion, making it the most favored control switch.

Correlation between Control Switch and Characteristics of Motion

Figure 4 shows the correlation between the control switch and the characteristics of motion based on the suitability assessment. Each correlation between control switch and characteristics of motion showed (from Figure 4) that for straight translation motion, the correlation was high for a joystick, and for frequent start/stop the correlation was high for a push button. For others, it was observed that a knob is highly related to circular motions. Figure 4 can be used as technical data when choosing suitable control switches for various robotized construction works.

Correlation between Productivity and Convenience

As can be seen in Figure 5, the assessment result showed that capability and functionality, functionality and safety, and safety and maintenance are all closely related to each other, whereas functionality and capability are related to efficiency from the perspective of productivity. Also, it shows that monitoring devices and characteristics of the work/the work environment are closely connected to the prevention of malfunctions from the perspective of convenience. Bodily characteristics show clear connections in capability and functionality from the perspective of correlation between productivity and convenience. It can be observed that prevention of malfunction is ultimately a requirement for improving capability since it is closely related to safety, functionality and efficiency. Also, it is shown that the characteristic of work and consideration of the work environment are requirements for functionality, safety and maintenance.

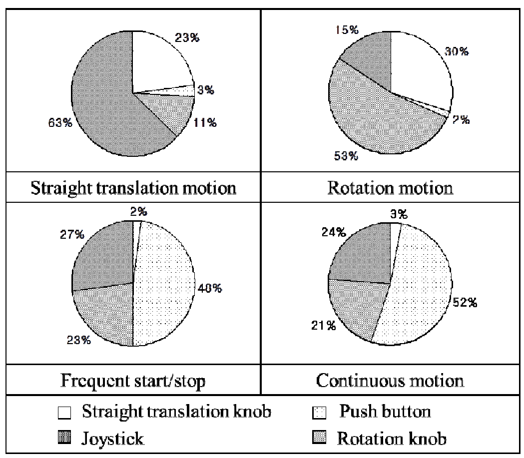

Figure 3 – Assessment of the control switches' suitability for the four characteristic motions

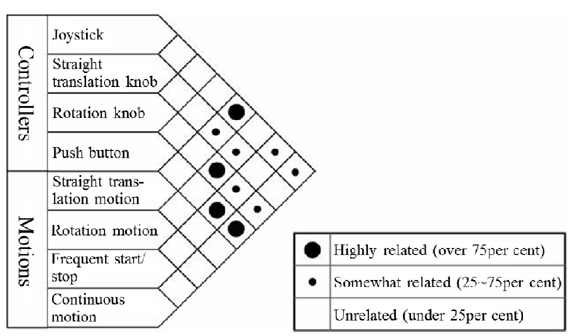

Figure 4 – Correlation matrix for the control switch and the characteristics of motion

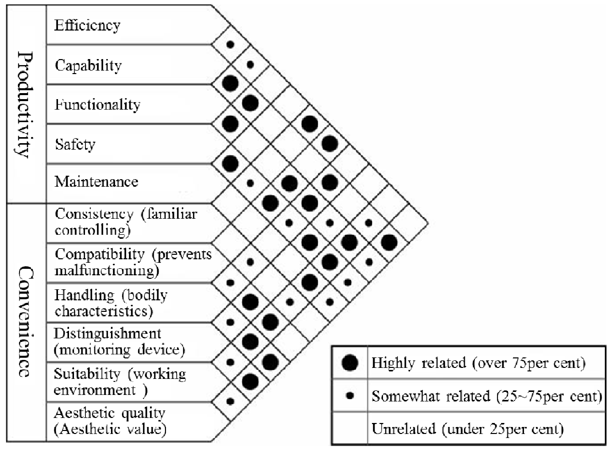

Figure 5 – Correlation matrix for productivity and convenience

APPLICATION; MANUAL ROBOT CONTROLLER FOR CURTAIN WALL INSTALLATION

Curtain walls are receiving much interest from the architecture sector recently, as a new form of building glass. This glass is relatively heavy and thus, installation of curtain walls by manpower can cause many problems, considering that the construction industry presently lacks skilled labor and harbors an aging workforce. Therefore, the curtain wall installation robot (Figure 11 left down) which promotes safety and improves productivity during construction was developed (Lee et al., 2006).

Analysis of working processes

Automatic curtain wall installation using robots is broadly classified into gripping, moving, aligning and assembling. The required characteristics of mechanical motion of the robots for each operation are as follows.

a. Gripping (an operation where a robot approaches the curtain wall which is on the ground and secures the curtain wall to itself using a vacuum suction device): Straight translation motion and rotation motion in the x axis direction, (Tx) and (Rx) respectively, and rotation motion in the z axis direction (Rz) are commonly used as shown in Figure 6 (left up). Also, frequent starting/stopping and continuous motion for each degree of freedom, as well as precise motion, are required.
b. Moving (an operation which lifts the curtain wall perpendicular to the ground with a mini-excavator and moves it to the place of work): Straight translation motion and rotation motion in the x axis direction, (Tx) and (Rx) respectively, and rotation motion in the z axis direction (Rz) are commonly used as shown in Figure 6 (right up). Also, frequent starting/stopping and continuous motion for each degree of freedom and precise motion are required.
c. Aligning and assembling (an operation which aligns and assembles slabs and already installed curtain walls after moving the curtain wall to the place of installation): Straight translation motion and rotation motion in the x axis direction, (Tx) and (Rx) respectively, and rotation motion in the z axis direction (Rz) are commonly used as shown in Figure 6 (right down). Also, frequent starting/stopping and continuous motion for each degree of freedom and precise motion are required.

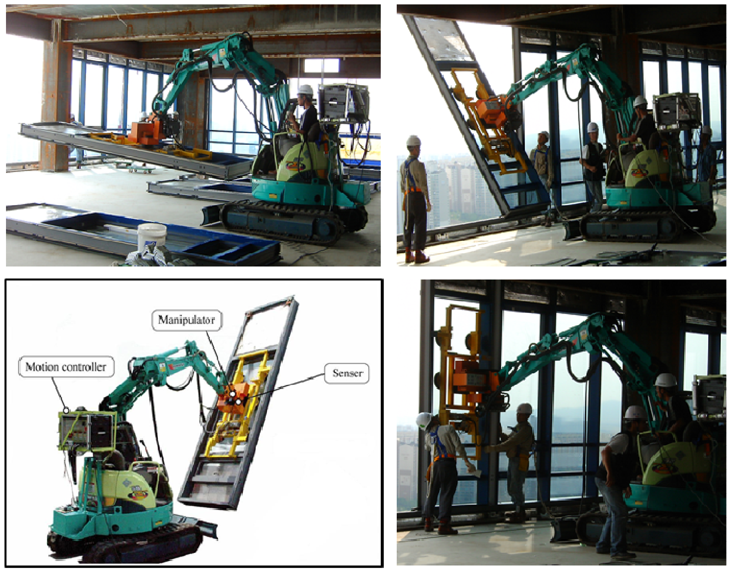

Figure 6 – Curtain wall installation robot & working processes

New Manual Robot Controller

The new manual robot controller was designed as shown in Figure 7 based on the directions of motion and analysis of the robot characteristics necessary for operating each process. A joystick was selected for 3 degree of freedom (straight-line motion along x and y axes, rotation about z axis) and push buttons were chosen as the control switches for precise motions and frequent starting/stopping. These switches satisfy frequent starting/stopping, continuous motion, straight-line motion and rotation conditions among the existing, commonly used control switches. The body of the manual robot controller was considered mobility and convenience for users, and it was also resistant to water or dust. The joystick which controls the direction of mechanical motion was located on suitable position of the robot controller, thus preventing malfunction of other control switches. The size of the controller was suitable for the purpose of protection against shock, and it becomes a convenience when the controller is held and operated with one hand. The location and shape of the buttons were user-friendly, and the buttons were located where they are easily recognized for each direction of motion. Figure 8 shows working time comparison of the proposed manual robot controller and the existing manual robot controller. Operation time means each time consumed in gripping, moving, aligning and assembling the curtain wall in Figure 8.

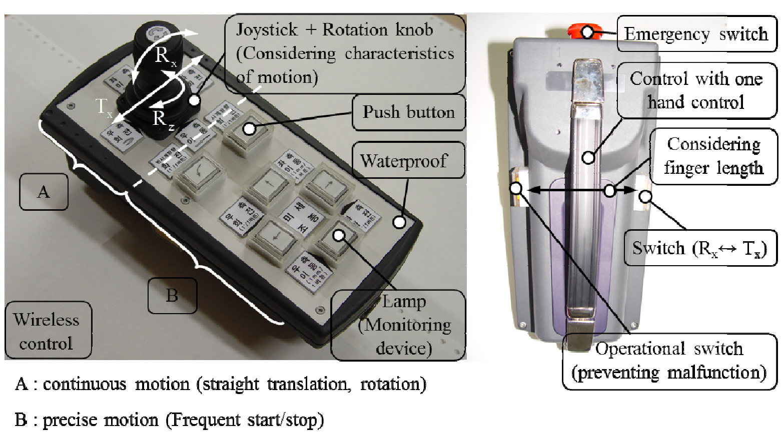

Figure 7 –New manual robot controller for curtain wall installation

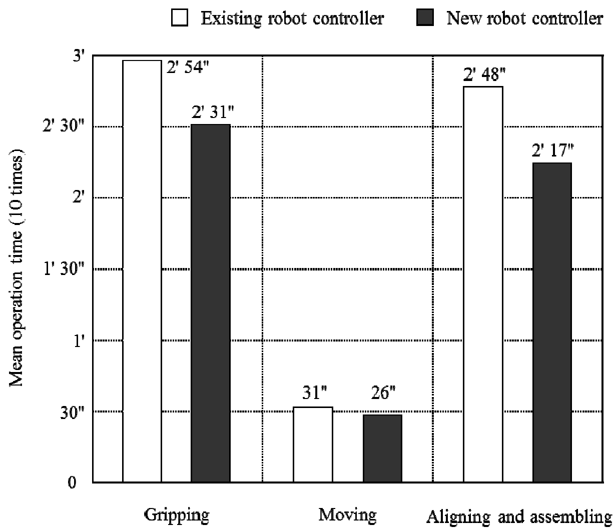

Figure 8 – Working time comparison of the proposed teach pendant and the existing teach pendant

CONCLUSION

Through this study, the suitability of control switches used in glazing robots in present construction sites was assessed. Also, the correlation between productivity and convenience was analyzed from the perspective of a manual robot controller. Through the analysis, design guidelines of a manual robot controller to improve productivity and convenience were prepared. These design guidelines can be used as teach pendant design criterions of a general automation system including a construction automation system. This is because factors of design are based on complaints and requests from site workers through questionnaires and interviews, and an approach which reflects their opinions was taken to prepare the design guidelines of a manual robot controller. Lastly, a new controller of the curtain wall installation robot was produced by proposed design guidelines. To verify the design guidelines, working time comparison of the proposed robot controller and the existing robot controller was executed.

ACKNOWLEDGMENT

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