MULTI-DOF (Degree Of Freedom) CONSTRUCTION ROBOT FOR A CURTAIN WALL INSTALLATION OF A SKYSCRAPER

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Abstract: Recently, the trend in architectural forms has been toward larger and taller building. The building materials, therefore, are getting larger and heavier as well. Typical construction machineries are, however, not adequate for handling these materials and most of the construction works have been still managed by a human operator. Construction processes are, therefore, fraught with a number of problems, including frequent accidents, high construction cost and heterogeneous construction quality; which is depended on the experience of the worker. In various construction sites, automation in construction has been introduced to address these problems. In this paper, the process of a curtain wall construction in the skyscraper is analyzed and proposed the Multi-DOF Construction Robot (MDCR) for this construction process. The need of man power can be reduced by using the proposed MDCR, the construction period and cost can be retrenched as well. The MDCR can be assured safety in the curtain wall construction site. The performance of proposed robot system (MDCR) was verified with the real application test in skyscraper construction site.

Keywords: Curtain wall, Skyscraper, Multi-DOF Construction Robot (MDCR), Modularization, a macro-micro motion manipulator, Human machine cooperative system

1. INTRODUCTION

Recently, the research on robot has a lively progress from the innovative development of high-technology. An industry robot is, therefore, applied widely to a manufacturing field such as an automobile industry [1]. In the same way, the application of construction automation system and robot has been considered to improve productivity and safety in construction industry. Compared with a manufacturing industry, the automation technique has not been applied due to the characteristics of a construction industry [2].

The current trend in building construction is toward taller and larger buildings. The building materials are, therefore, becoming larger and heavier as well. Many of the types of equipment used to handle these materials are outdated, and most of the construction work is managed by a human operator. Construction work is, therefore, fraught with a number of problems, including frequent accidents, high construction cost and heterogeneous construction quality which depend on the experience of the operator [3]. To solve these problems, it is necessary to introduce the construction automation system and robot. Furthermore, humankind has expended its territory. It now reaches into space and under the sea. Construction equipment, therefore, must be developed to handle these new construction challenges [4].

Generally, a construction robot has been developed for higher productivity and better safety in many different areas of construction [5, 6]. As the trend of building construction is changed, the curtain wall to determine a building image is becoming the object of many concern in the constructing a building field. A curtain wall is one of materials for outer wall construction method. It is appropriate for super tall buildings (or skyscraper). For this reason, an automation system and robot for curtain wall

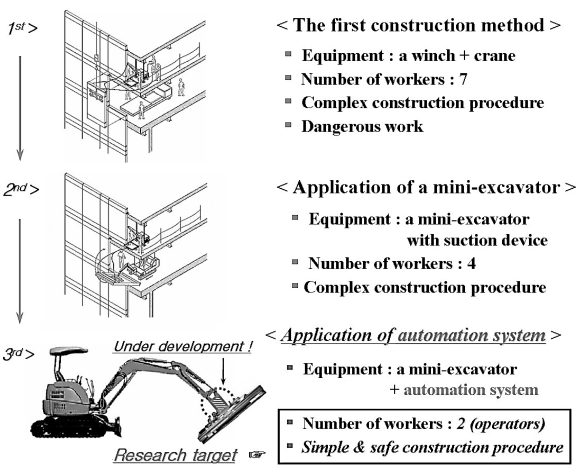


Figure 1. The development procedure of curtain wall installation method

installation in a skyscraper construction procedure must be developed.

Up to now, the development of curtain wall construction is classified into 3 processes such as Figure 1. In the first construction method, a curtain wall is installed using a winch and crane, as well as many workers. Its procedure is complicated and slow; as well, it is dangerous for the workers. In the second construction method, to improve the procedure, a commercial mini excavator with suction device is applied. The suction device has one rotation mechanism which is operated by manual manipulation. Figure 2. shows the suction device.

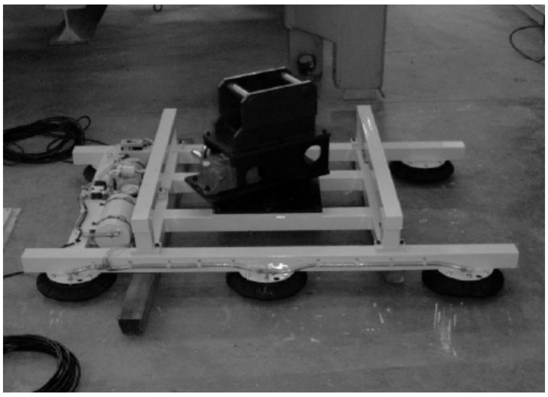


Figure 2. The suction device

Through use of the mini excavator system, a curtain wall can be moved to the assembly point easily. This system also reduces the number of workers and the amount of construction period. The curtain wall assembling, however, must still be operated by a construction worker. The authors of this paper propose a human machine cooperative system which replaces the suction device in the mini excavator system. The system under developing now and it is applied to the third construction method.

This study considered these processes and conceived of a way to employ a robot in the installation of the curtain wall in a skyscraper construction work. The use of robots at construction sites can reduce the need of human involvement. Construction period and cost can be reduced as well. An important aspect of the use of robots at construction sites is prevention of accidents [7, 8].

2. ANALYSIS OF AN EXISTING INTALLATION METHOD; THE MINI EXCAVATOR SYSTEM

The current curtain wall installation method must be analyzed in order to design a robot. The mini excavator system is composed of a suction device and a commercial mini excavator. A suction device holds the curtain wall with a rotation mechanism. An excavator is used to move the curtain wall to the assembly point. Figure 3. shows the mini excavator system.

Figure 3. The mini excavator system

2.1 Definition of a coordinate system of curtain wall

Before analysis of the current curtain wall construction method can be conducted, a coordinate system must be defined as presented in Figure 4. The origin of the coordinate system is located in the center of mass of the curtain wall. T represents translation and R represents rotation.

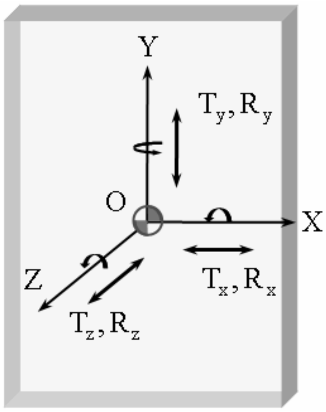


Figure 4. A coordinate system of curtain wall

2.2 Analysis of an existing installation method according to the procedure

2.2.1 Suction

By using the suction device on the end of a mini-excavator, the curtain wall is held in place. The required DOF is R_z to align with the excavator.

Figure 5. The suction process

2.2.2 Movement

The curtain wall is moved toward an assembly point by a mini-excavator. The required DOF are R_z to avoid obstacles.

Figure 6. The movement process

2.2.3 Placement

The position and orientation of a curtain wall is adjusted by a R_z rotation mechanism. The required DOF is T_x, T_y, T_z, R_x, R_y, and R_z. The utilizable DOF in a mini-excavator is T_y, T_z, and R_x. The utilizable DOF in the rotation mechanism is R_z. A residual DOF is handled by a worker.

Figure 7. The placement process

2.2.4 Installation

The mini-excavator is separated from the curtain wall. Then, the final assembly work is executed by a worker. The required DOF is T_x, R_x and R_y.

Figure 8. The installation process

3. A CONCEPTUAL DESIGN OF MULTI-DOF CONSTRUCTION ROBOT

3.1 Determination of essential DOF

In the installation of a curtain wall, the required DOF is T_x, T_y, T_z, R_x, R_y, and R_z. The utilizable DOF in the mini excavator is T_y, T_z, and R_x. Through the experience of install operator, essential DOF in the construction robot is T_x, R_y, and R_z. Under developing system, therefore, has a three-link RPR manipulator such as Figure 9.

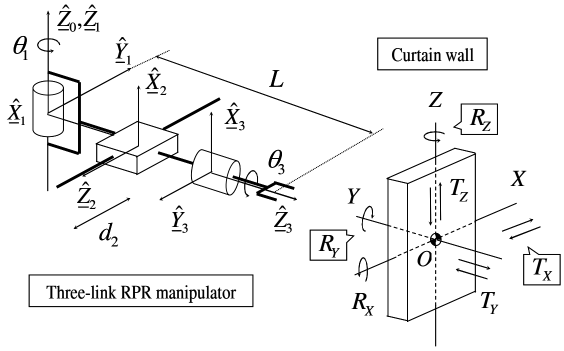


Figure 9. Schematic diagram of a three-link RPR manipulator

3.2 Consideration of overturning

One of the most important considerations at a construction site is the safety of human workers. If an excavator loads over weight, it will be overturned [9]. To prevent overturning, safety tests were considered, as presented in Figure 10.

Figure 10. The overturning test of a mini excavator

When the boom and arm spread parallel with the ground, a heavy material could be lifted up to 500 kg by a commercial mini excavator. The weight of a curtain wall is 300 kg from Table 1. The system under development, therefore, must weigh less than 200 kg. Through the overturning test, the boundary condition of robot design is established, such as table 2. An importance of the establishment of boundary condition in robot design is prevention of accidents and troubles.

Table 1. Specification of curtain wall

Specification	Data
Weight of curtain wall, [*kg*]	300
Width of curtain wall, [*m*]	1.8
Height of curtain wall, [*m*]	3
Thickness of curtain wall, [*m*]	0.2

Table 2. Specification of curtain wall

Design spec.	Data
Total weight, [*kg*]	200
Weight of each module, [*kg*]	50
Weight of suction device, [*kg*]	50
Total length, [*m*]	0.50
Translating velocity, [*m/s*]	0.05
Rotating velocity, [*rad/s*]	0.209 (2 [*rpm*])

3.3 A design of system specification

The system under development can be used not only in curtain wall installation but also in other construction work. This system, therefore, is modularized to add or remove DOF. Table 3. shows the diagram of the modularized design.

Table 3. Schematics of a modularized 3-DOF manipulator

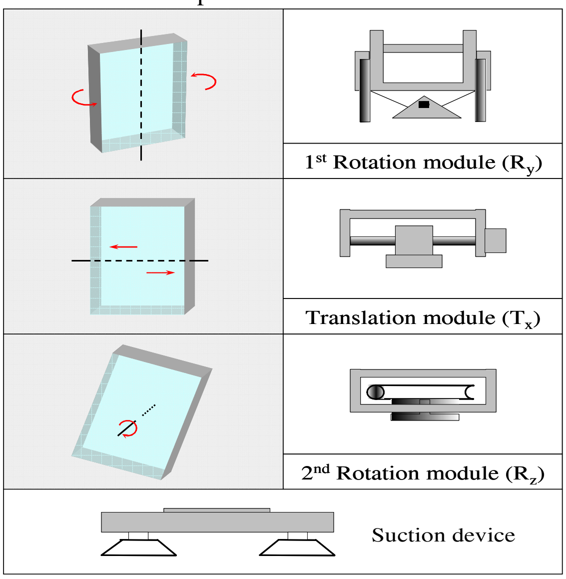


Table 4. Required force and Torque in each module

Module	Data	
1st Rotation(R_y)	Motion Range	±20°
	Required Torque	196.4 [Nm]
Translation(T_x)	Motion Range	±0.25m
	Required Force	20.0[N] (No Friction)
2nd Rotation(R_z)	Motion Range	±270°
	Required Torque	725.54 [Nm]

The specification of each module is determined by analysis of the current curtain wall installation work. In the design of a system, the required torque and force have to be calculated to select the proper actuator, as presented in Table 4. The actuator of each module is selected by comparing AC servo motor with hydraulic motor, such as Table 5.

Table 5. Comparison AC Servo Motor with Hydraulic Motor

	AC Servo Motor	Hydraulic Motor
Actuator	· Easy control · Extra power transmission device · Low accuracy (a reduction gear) · High speed operation	· Hard control · High power · Refrigerator needed · Low speed operation
System	· Simple-wiring · A Cheap unit	· Complex-wiring · A expensive unit · Oil leak

4. REALIAZAION OF THE MULTI-DOF CONSTRUCTION ROBOT

The curtain wall installation system overview is a macro - micro motion manipulator. A mini excavator is considered to be the macro motion manipulator. The system under development is considered to be a micro motion manipulator. Figure 11. shows the micro motion manipulator which is under development.

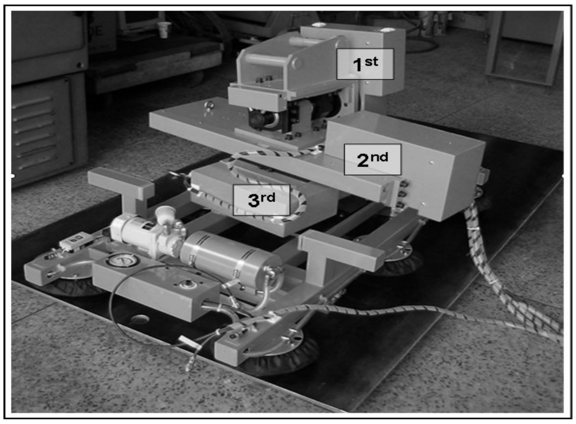


Figure 11. The micro motion manipulator

The arrangement of each module is determined by analyzing of characteristic, such as Table 6. Figure 12. shows the macro-micro motion manipulator.

Table 6. A characteristic of each module

Characteristic	High ⟷		Low
Frequency of use	3rd	2nd	1st
Durability for a load	1st	2nd	3rd
Moment of Inertia	3rd	1st	2nd

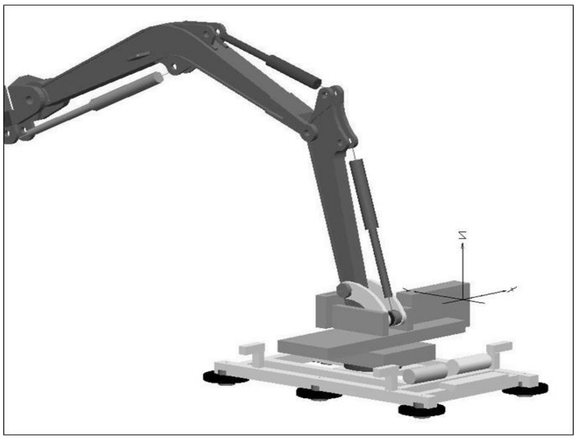


Figure 12. The macro - micro motion manipulator

5. CONTROL STRATEGY

Generally, the fully automated system is not suitable for construction work due to frequently changed construction environments. A human machine cooperative system is, therefore, suitable for construction work [10, 11]. It is an interactive system in order to cooperate with the human, as presented in Figure 13.

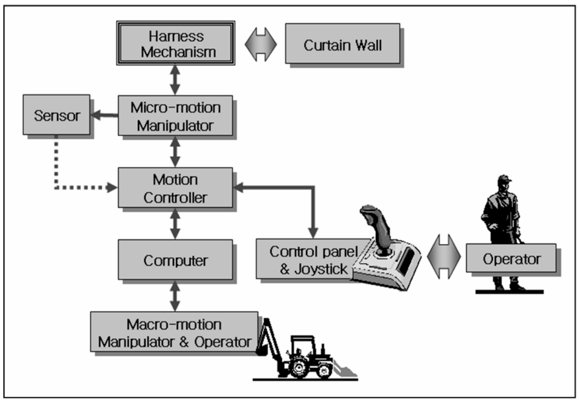
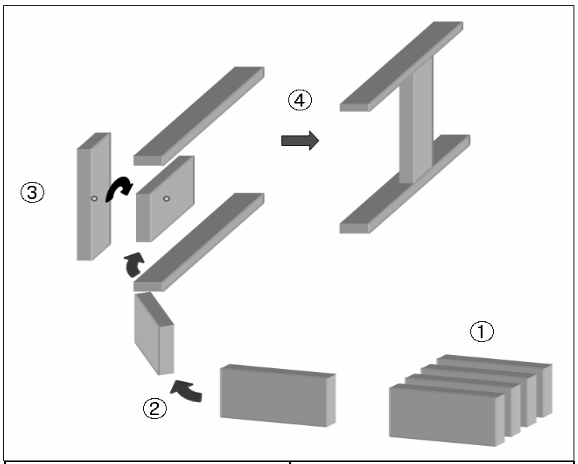


Figure 13. A human machine cooperative system

6. SIMULATION OF INSTALLAION

Before the developing system is applied to the construction site, simulation is needed to estimate goal achievement for a conceptual design, such as Figure 14. Through the simulation of installation, a new installation process is established, as presented in Figure 15.

Figure 14. Simulation of curtain wall installation



① Loaded Curtain-wall	② Moving
③ Rotating	④ Assembly Complete

Figure 15. Schematic diagram of curtain wall installation

7. HUMAN ROBOT INTERACTION

For adequate (or optimal) productive gains, a human should have a minimal capacity or skill level to effectively and efficiently work with the robot system. The job skills and experience, therefore, are defined from a diagram of working process as shown in Figure 16. The operators require more skill and knowledge than the traditional operator.

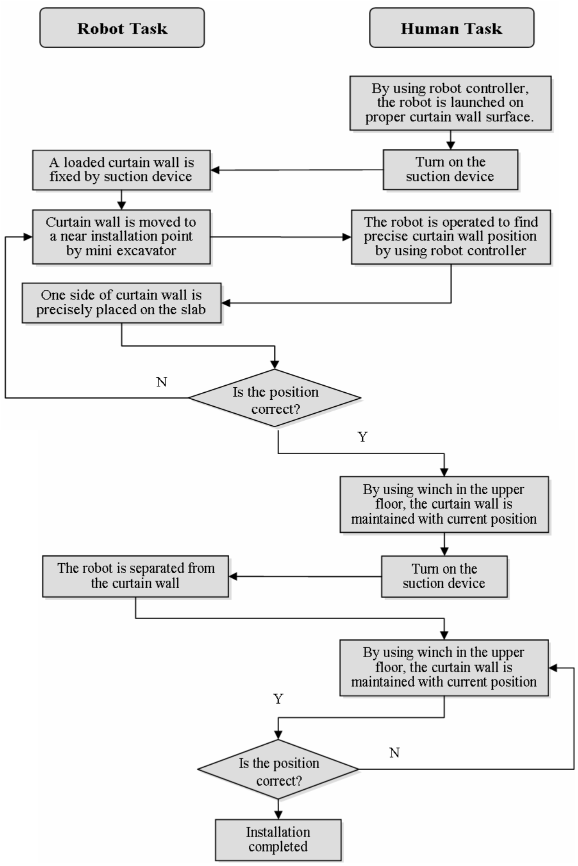


Figure 16. Human robot interaction diagram

8. CONCLUSIONS

The ultimate goal of the proposed system is for human-machine cooperation. The robot is commanded/operated through human force; in turn, it assists the human operators [12].

The system described in the present study is one step on the way to full automation. There is still a long way to go; however, the research and development continues. The advantages of proposed system include the following:

- ✓ Simple and precise construction procedure
- ✓ Reduction of the numbers of human workers
- ✓ Safety assurance
- ✓ Retrenchment of the construction cost and period
- ✓ Homogeneous construction quality

Much of the automation in construction has been developed for outdoor work. The proposed robot is being developed for curtain wall construction work at indoor sites. The micro-motion manipulator is modularized to allow for addition or removal of a DOF. Furthermore, the proposed robot can be applied to other construction work by exchanging the end-effecter.

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