Advanced Robotics in Civil Engineering and Construction

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Abstract- Robots are being used in increasing numbers in manufacturing throughout the world. The expanded use of industrial robots in manufacturing and the increased projections of greater numbers in the future has resulted in a greater interest by the construction industry. As a key technology, construction robots are expected to improve working conditions, reduce accidents, and increase construction productivity. Robotics in the construction industry is a young and fast growing interdisciplinary field.

I. INTRODUCTION

While the application of robots in the manufacturing is now well established, the range is continually expanding into other fields such as Civil Engineering (CE). Within the CE, application of robotics in construction engineering has been very active. Robotics in the construction industry is a young and fast-growing interdisciplinary field, in which many researchers are challenging to create productive, cost efficient, and smarter machines.

Although the construction industry so far has managed to develop highly productive systems without the help of robots, but there are specific areas of application that the industry would benefit from robots application. The main ones are the application of robots in construction processes which can produce better quality with faster production. Another application area is in hazardous work environment that would be dangerous for a human operator. The robots can be also used to perform construction tasks that are boring or tiring for the human operators [1].

In most cases, robots are developed to accomplish specific construction tasks. However, in order to obtain much benefit of robots, it is necessary to approach changing the whole construction system like factory automation in the manufacturing industries. In another words, newly developed construction systems should achieve the building design and construction planning just suited to robots.

Four key requirements for a successful application of robotics in construction industry are: increase in productivity, technological feasibility, quality improvement, and meeting the needs of the contractors or subcontractors [3, and 4].

The objective of this paper is to introduce some of practical robots developed in the construction industry. Currently research is in progress in Building Construction (e.g., Fireproofing spray robot, Steel beam positioning manipulator, Radio control auto-release clamp, Ceiling panel positioning robot, Multi-purpose traveling vehicle for concrete slab finishing, Concrete floor finishing robot, Exterior wall painting robot, Automatic silo lining system; Civil Works (e.g., Cast in situation substructure system-giant, Shield tunnel auto drive system); Nuclear Plants (e.g., One piece reactor removal system, Activated concrete cutting robot); Manufacturing Facilities (e.g., Clean automation system robot); and Space Development (e.g., Construction robot in space, Lunar base construction robot). This paper describes some of the successful robots.

II. CONCRETE FLOOR FINISHING ROBOT

Concrete floor finishing work consists of leveling, wood floating, and trowel-finishing steps. The final trowel-finishing step is the most difficult for the worker because the worker must push a trowel on the wet concrete floor in an awkward posture for a long period of time. Furthermore, the number of skilled workers for concrete floor finishing work is decreasing. So, it has been difficult to gather enough skilled workers at construction sites.

The robot can be operated by radio remote manipulation. The hardness of the concrete surface to be finished is not uniform in the finishing area. The parameter of the robot should be changed according to the hardness of the surface, which is difficult to measure, therefore, a remote-control system was adopted.

The main features of this device are its fine finishing accuracy, close contact between the trowel and concrete face, and the trowel load can properly be adjusted according to how much the concrete has grown hard. The angle between the concrete surface and the trowel can be adjusted by a cam mechanism. This angle is changed according to the hardness of the concrete surface to be finished. Other features of this machine are that it is easy to install, operate, and clean it away [2, and 5].

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III. CEILING PANEL POSITION ROBOT

Ceiling construction for office buildings, hotels, and other commercial buildings is accomplished by using "plaster board" panels, which are made of plaster and covered with paper. The plaster board ceiling construction method accounts for about 70% to 80% of the ceiling construction market in Japan. A typical mid-size office building, for example, with 8 floors and 5,000 m^2 (53,820 ft^2) requires 400 panels for each floor, totaling 3,200 pieces which must be set one by one.

The procedure for ceiling construction requires temporary scaffolding to be erected all over the floor and then be cleared away for the next procedure. Human workers must assume an undesirable posture for the panel setting work. The workers must raise heavy and large sized panels over their heads for placement against the hanging ceiling flat bars. Repetition of this work over a long period of time exhausts the workers. Sometimes ceiling construction results in a delay of the total building construction period because of the shortage of skilled panel setting workers.

The CFR-1 is a typical robot developed for ceiling panel positioning which consists of a panel carrier which can be separated easily when transported. The CFR-1 has four degrees of freedom, 300 kg (660 lb) weight, carrying capacity of 20 panels, work capacity of 25 panels/hour, and working travel speed of 3 m/min (10 ft/min).

Ceiling construction work using the robot is accomplished as follows. The fully loaded panel carrier is attached to the robot (about 20 panels), and the robot is positioned under the location where the panel will be set. The robot uses the panel holder to remove one panel from the panel carrier and lifts it into position among the hanging ceiling flat bars. The robot places the panel in correct position using the X-Y horizontal table automatically assisted by the compliant mechanism. Then, a worker fixes the panel using an air screw driver. The robot travels to the next position to set the next panel.

IV. ACTIVATED CONCRETE CUTTING ROBOT

Many nuclear facilities are reaching a decommissioning stage which requires the disposition of the plant. In these facilities, the reinforced concrete of the biological shield surrounding the reactor core is usually irradiated due to the direct activation from the neutron flux. The cutting robot for dismantling biological shield is developed to remove the inner activated layer of the concrete biological shield by concrete sawing and core stitch drilling.

Total height of the robot is 500 cm and it has 15 tons weight. It uses a programmable sequence control system with sensor feedback. Activated concrete removal sequence by this robot consists of: a) horizontal cutting, b) concrete core drilling, c) vertical concrete cutting, and d) removal of the cut concrete blocks. To reduce tool changing time, the robot is equipped with two arms, one for sawing machine and the other for coring machine fitted in opposite directions and actuated simultaneously.

To develop a practical robot, first a prototype robot was designed and applied in a cutting test. Measurements were taken of cutting depth, cutting speed, electrical power consumption, wear rate of diamonds, quality of the black and core coolant, quantities of dust and slurry produced, and reliability of the model.

V. EXTERIOR WALL PAINTING ROBOT

This robot is an automatic sprayer for exterior wall painting that can perform spray coating on exterior walls of medium and multistory buildings. Its main purposes are: sealer coating, material spraying, and top coating. It can cope with materials to be sprayed and the finish patterns of the main materials. Furthermore, it needs only one operator on the ground and provides an enhanced production rate about five times that of conventional methods. It gives an excellent finish comparable to skilled workers.

The robot is usually is hung by wire ropes from a trolley running on a traveling rail installed on the rooftop and set at the top of the wall. Then, the spraying work is started by wireless remote control and reciprocates the automatic spraying gun on the traverser. In this manner the gun can perform automatic spraying at the desired width of up to 3 m (9.84 ft) in each traverse movement. The operation process consist of the following steps: The material is loaded; The automatic coating program is set from the panel; Operation through the controller.

The system has a production rate of about five times that of conventional methods [2]. It needs only one operator on the ground where in conventional spraying work at least two operators were needed. This device eliminates dangerous spraying work at high building elevations and greatly enhances safety. It allows early dismantling of the scaffold, enabling an early start of the final work such as construction of the outer structures.

VI. AUTOMATIC SILO LINING SYSTEM

The major causes of reductions in the air-tightness capacity of a reinforced concrete silo are the "cracks" arising in such areas as structural walls, hopper, and the upper slab. This system involves automatic spraying of the lining with single-liquid type hydrophilic urethane resin which possesses desirable viscosity characteristics. It offers a better compatibility with the base material. This material is applied over the cracks once they have been injected with epoxy-resin.

VII. FIREPROOFING SPRAY ROBOT

Rockwool spray work for fireproofing steel structural members is a hazardous construction job. A robot is developed to provide a safer work environment for spray workers. While spraying, the robot moves parallel to a steel beam at a constant distance measured with a pair of ultrasonic sensors. Compared to conventional methods, the work environment is improved and work speed is increased without the use of scaffolding.

An off-line teaching system is available. It is a direct teaching method which is executed by having the operator grasp the robot arm directly and guide it through the spray sequence. This is a common method for a play back robot.

VIII. RADIO CONTROL AUTO-RELEASED CLAMP

Radio Control Auto-Release Clamp is developed for improved safety and production rate of steel frame construction work. The robot is used in steel frame construction work as a kind of lifting device. It has lifting tolls (clamps) which apply to columns or beams of steel frame and can be automatically detached by radio control. It has 250 kg (550 lb) weight, and 12 t (13.2 tons) lifting capacity. This device is commercially available and it is practically applied in steel frame construction for many buildings. It has provided a high effectiveness in improving safety and production rate of construction.

The system has a double locking mechanism for safety at the time of detaching operation. Operation procedure is that first the column is grabbed by the lifting tool utilizing a bolt hole in the column, locked by a worker and lifted up. It is carried by a crane, lowered to the position, and after the column is fixed in position, the lifting tools are automatically unlocked by a wireless remote controller.

Main features and advantages of the system are:

1) Using this device, it is no longer necessary for a worker to climb up to high places to remove lifting tools.

2) the operation can be accomplished within a little more than 16 seconds which used to require several minutes in the past.

3) The lifting tools (clamps) are light and easy to handle, so they can easily be attached by hand to the object to be lifted.

4) It is not only applicable to columns and beams of steel frame, but also to curtain walls and units of steel reinforcement.

5) It has safety locking systems with a double locking mechanism [2, and 4].

IX. SUMMARY AND CONCLUSIONS

The goal of research in developing construction robot is to build robots which are more flexible, adjustable, and able to cope with constantly changing construction environments. Research and development in construction robots is intended to extend present capabilities of conventional equipment to an integrated and fully automated system. An ancillary benefit of this type of research is an understanding of the key problems that need to be solved in construction engineering.

As with any technology, new solutions bring new problems. One of the most serious problems currently facing automation in the construction industry is the integration of information. This integration must occur in a cost effective and productive manner without loss of current construction functionality. These robots represent the integration of many different ideas and technologies into a working system. The challenge of building construction robots is a challenge of integrating not only robot components, but also of integrating construction experiences, ideas, and technology.

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XI. REFERENCES

[1] Albus, James S. "Trip Report: Japanese Progress in Robotics for Construction," *International Journal of Robotics,* Vol. 2, No. 2, pp. 103-112, 1986.

[2] "Construction Robot," *Technical Reports,* Shimizu Corporation, Technology Division, Tokyo, Japan, 1987.

[3] Kangari, R., and Halpin, D. W. "Automation and Robotics in Construction: A Feasibility Study," *Proceedings of the 5th International Symposium on Robotics in Construction,* Tokyo, Japan, Vol. 1, pp. 161-167, June 6-8, 1988.

[4] Ueno, T., Kajioka, Y., Sato, H., Yoshida, T., and Tsutsui, R. "Research and Development on Robotic Systems for Assembly and Finishing Work," *Proceedings of the 5th International Symposium on Robotics in Construction,* Tokyo, Japan, June 6-8, Vol. 1, 279-288, 1988.

[5] Ueno, T., Maeda, J., Yoshida, T., and Suzuki, S. "Construction Robots for Site Automation," *Proceedings of the International Joint Conference on CAD and Robotics in Architectural and Construction,* Marseille, France, pp. 628-638, June 25-27, 1986.