ROBOTIC PERFORMANCE OF INTERIOR FINISHING WORKS: DEVELOPMENT OF FULL-SIZE APPLICATIONS

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ABSTRACT: *The paper describes the technological development of full-scale robotic execution, at construction sites, of several types of interior finishing tasks, the latest stage in the evolution of a multipurpose interior finishing robot. The robot will perform various building tasks, by adaptation of a mobile carriage, working tools, material feeding systems, and control algorithms, to a universal articulated arm.*

For execution of the various tasks, the present stage is designed around a standard, off-the-shelf industrial robot with 6 degrees of freedom mounted on a three-wheeled semi-automatically guided platform. In all its applications the robot arrives at a predetermined work station, calibrates itself with the aid of sensors in respect of both the assigned work area and the location of prearranged materials, and then performs its task.

Three types of tasks were examined: (1) painting of walls and ceilings, (2) tile-setting on walls, and (3) building of partitions and walls with lightweight building blocks.

These tasks are discussed with regard to the general concept of a robotized application, the solution adopted and further refinements - under development or envisaged in the future. The paper is illustrated by slides and a videotape.

INTRODUCTION

The possible employment of a building robot in the execution of various interior finishing tasks on construction sites was examined at the National Building Research Institute in the framework of a multistage R&D project. The robot, an articulated arm of appropriate reach and configuration mounted on a mobile carriage, was intended either to navigate autonomously or to be guided from one work station to another, carrying out its preassigned task at each.

Its end-effector, material feeding system, and a control program, were to be designed separately for each task. The main stages of the evolution of the robot were outlined as follows:

(a) Development of the concept of a multipurpose interior finishing robot.

(b) Experiments with a small-scale robot.

(c) Full scale experiments with a suitably adapted industrial robot.

(d) Development of a specialized prototype.

The first two stages were described in detail in [1] and [2], respectively. The third stage is the subject of the present paper. Three full-scale applications of robotic execution were examined: (a) spraying paint or plaster on walls and ceilings, (b) attaching ceramic tiles to walls, (c) building interior walls.

In the following sections, the main framework of the multipurpose robot and its adaptation to these three building tasks, are described under the following headings:

- general concept.
- actual execution.
- further refinements.

The project is still at an intermediate stage, and some applications are more advanced than others. Technical details are described in general terms only, and illustrated with slides and a videotape.

THE ROBOT

The full-scale applications of various types of robotized interior finishing tasks were examined with the aid of an industrial robot, GMF/S700, an articulated arm possessing 6 degrees of freedom. The reach of this robot is 1.55m and its payload 30 kgf. Although this robot differs from the desired prototype of a more efficient configuration, to be developed in the next stage, it has proved to be very useful in simulating full-size robotized building activities.

The robot was mounted on a three-wheeled mobile carriage measuring 0.85x0.85m. At present, the carriage can be guided by remote control, but at a later stage it will be able to autonomously follow a preprogrammed path. The robot is equipped with an array of touch sensors, with which it can determine the location of the tool with respect to the work surface. At a later stage it will be equipped with additional sensors for navigation and for the avoidance of obstacles.

The stage described in the present paper had two main thrusts:

(1) **Development of autonomous mobility and navigation of the robot between work stations.** The sequence of the stations and their locations with regard to the work scene, is at present being programmed off-line. At each station the robot calibrates its location and point of work initiation by verifying the real dimensions of the given space with the aid of sensors. In a more advanced version, the controller of the robot will interpret real-time sensor measurements of the total work space to validate an existing plan, or even independently generate the complete movement and work program.

(2) **Actual performance of the interior finishing tasks.** For each task an effector and material supply systems were devised. As noted before, three applications have already been examined:

(a) spraying paint or plaster on walls and ceilings,

(b) setting ceramic tiles on walls,

(c) building interior partitions.

The applications are examined here with respect to their technological feasibility, while their economic aspects will be discussed in a separate paper.

PAINTING OF WALLS AND CEILINGS

General Concept

At each work station the arm moves, or is led, to a starting point on the wall to be painted (or plastered). There it calibrates itself and proceeds to paint the assigned area, usually with maximum utilization of its work envelope. The robot then moves to the next work station (as determined by the program), where it performs its task in the same way. Ceilings are painted in a similar manner, either separately or in conjunction with wall painting.

Execution

The robot is equipped with a spraygun, whose ON/OFF switch and flow control nozzle are operated by output connections of the robot's controller. These outputs are activated, in turn, by the painting program routine, which can also accept and react in real time to sensor information transferred via input connections while the controller is in interrupt mode.

The distance of the TCP (Tool Center Point) from the surface of the wall, its orientation, and its speed of movement, are programmed to ensure a uniform coverage of spraying strips with paint.

Painting is done in horizontal or vertical strips, with some overlaps between them.

Obstacles (e.g. doors and windows) are skipped or avoided, either by pre-programming their locations at the beginning of the job, or by detecting them, in the course of the work, with the aid of sensors attached to the arm. Combinations of the two alternatives are also possible.

In order to ensure the uniform flow of paint and also to facilitate an uninterrupted material supply, a small buffer bin was connected to the gun, in addition to the large replaceable bins mounted on the robot's carriage.

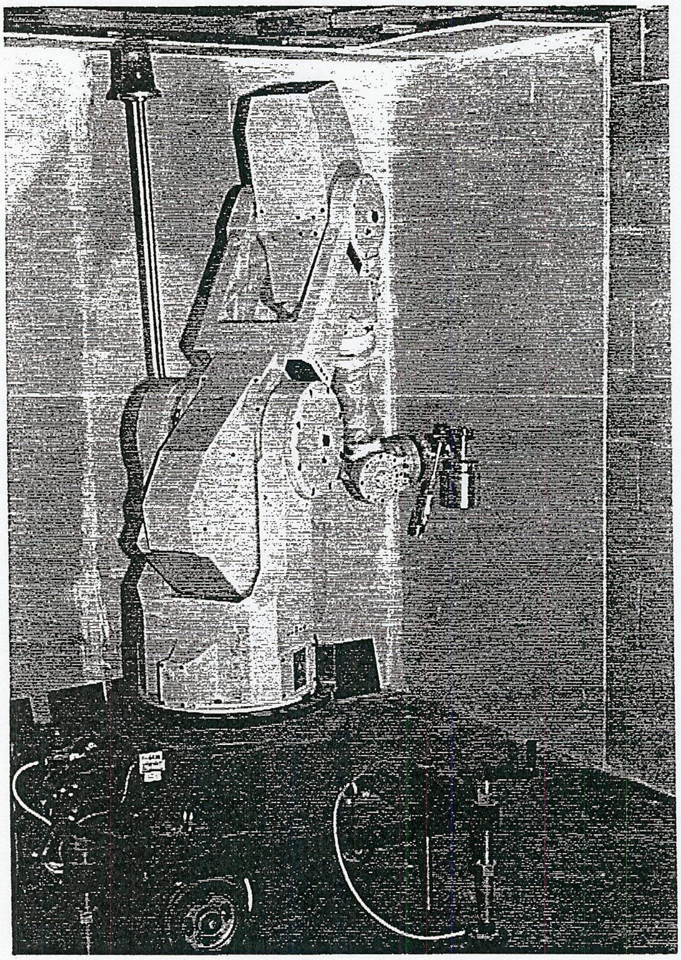

Fig. 1 – Painting/plastering of walls with the robot

Further Refinements

Further work in this task area includes experiments with various types of materials on different wall surfaces and a real-time quality control. The latter involves the measurement of paint thickness with consequent control of the material flow and of the distance of the spray gun from the wall surface.

ATTACHMENT OF CERAMIC TILES

General Concept

Tile setting consists of three major sub-tasks:

(a) Picking a tile from a box or a cartridge.

(b) Receiving the correct dose of cement or glue material on the reverse side of the tile or on the wall.

(c) Placing each tile very accurately in its place on the wall and keeping it there for several seconds until the cement/glue has set.

This task must be very precisely performed. Therefore, before the actual tile setting, the surface of the wall must be checked for conformance to a pre-specified tolerance. For this purpose, the robot starts by calibrating itself against the work scene by checking the plane of the wall, locating corners, and validating dimensions. It will detect and call attention to surface imperfections, and will finally ask the operator for corrections or for his O.K. to start the job.

Execution

The main features of the manner of execution adopted are as follows:

a. The tile boxes are placed within a confined pre-designated location beside the robot.

b. The tiles remain inside their original packages, which are opened face up.

c. The robot's arm is equipped with a vacuum gripper and a limit-switch. It leans toward the box until it reaches the top tile, which is then picked up approximately at its center.

d. The arm takes the tile to the gluing station, where it is dropped into a right-angled accurate corner and receives the correct dose of glue; it is then picked up again in the exact position in which it is to be attached to the wall.

e. From the gluing station the tile is taken directly to its precise location on the wall.

f. While the tile is being pushed against the wall, the excess glue is squeezed aside, until the tile surface precisely merges with the predefined plan.

g. A delay of several seconds provided before the vacuum is released is sufficient for the glue to set and hold the tile in place.

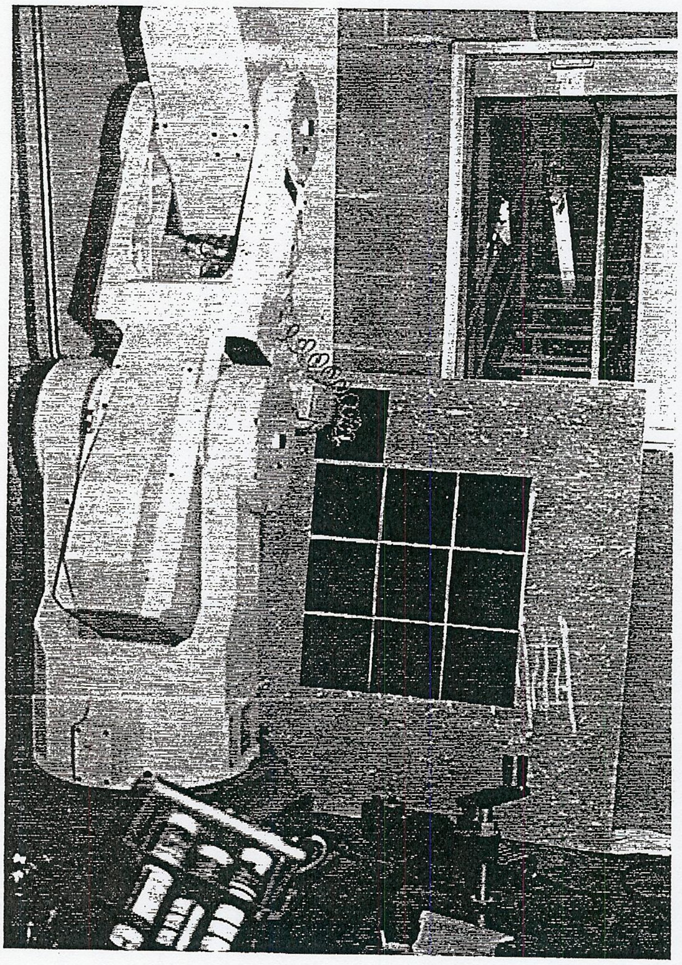

Fig. 2 - Attachment of tiles with the robot

Further Refinements

A special carriage is under design, that will house both the gluing station and several boxes of tiles. With this carriage it will be possible to execute special tile patterns on the wall by combining two or more types of tiles. Other improvements of the gluing process are also envisioned.

BUILDING OF INTERIOR WALLS

General Concept

Interior walls are built of lightweight blocks by a "dry" method, i.e. the blocks are placed by the robot without the customary adhesive layer of glue or mortar. Upon completion by the robot, the wall is strengthened by the injection of mortar or the application of special plaster to ensure its subsequent performance as one monolithic unit. The robot has to carry out a fairly accurate depalletizing task in order to release the blocks from their standard packages, which are placed beside the wall to be built at preplanned locations. Alternatively, a gluing station, somewhat similar to the tile application, can be employed.

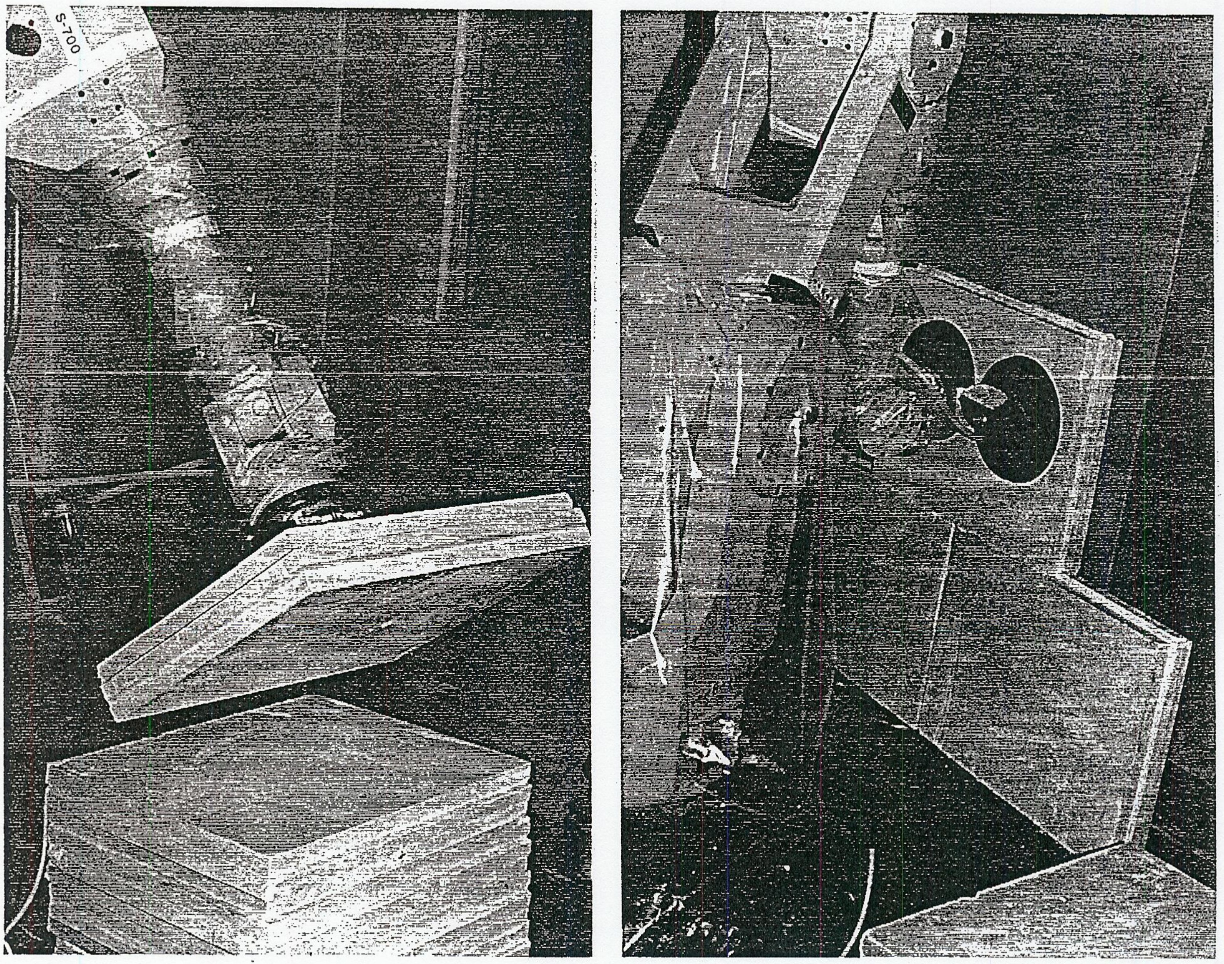

Fig. 3 - Building of walls with the robot

Execution

The wall is built of lightweight large gypsum blocks, 0.70x0.50m in size and weighing 27 kgf each. The blocks have interlocking edges, which facilitate their accurate positioning. Several dimensions of blocks are used in order to obviate the need for adjustment to room dimensions during the actual wall building. The blocks in their pallets are placed in a horizontal position, and a dual vacuum gripper is used for their pick-and-place operation. Several methods of posterior wall reinforcement, in lieu of mortar joints, were examined, but they are outside the scope of this paper.

Further refinements

The ultimate size and profilation of the blocks to be used are still under examination. The size and width of the blocks must be such as to ensure the operational efficiency of the robot, the stability of the wall until its reinforcement, and some dimensional flexibility in order to enable them to conform to different wall sizes without on-site block cutting.

Other elements of the system, which have not yet been fully developed, include the precise structure of pallets for the blocks and the interface between the wall and its later subsequent reinforcement, both executed by robotized methods.

CONCLUSIONS

Three full-scale applications of the robotic execution of building tasks were examined, within the general context of employing a multipurpose interior finishing robot. The examination focused on the adaptation of the robot to the performance of building tasks, and the adaptation of building technology and processes to the constraints of robotic performance.

The technological development and evaluation form a basis for a feasibility study of robotic equipment. By comparing the cost, the productivity, and the speed of robotic versus manual execution of interior finishing tasks, it is possible to determine whether, and under what conditions, the employment of robots on construction sites is feasible and desirable.

REFERENCES

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