PRACTICAL USES OF PAINTING ROBOT FOR EXTERIOR WALLS OF HIGH-RISE BUILDINGS

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ABSTRACT

The robot automates the operation painting on exterior walls of high-rise buildings. The robot is designed to ensure safety during work at high elevations, assure the quality of the coating, enhances efficiency and maintain the privacy of guests in the building. At the Shinjuku Center Building (54 above-ground storeys, 220 m in height, 100,000 m^2 of coating) one of Tokyo's high-rise buildings, an operation to paint the exterior walls has been in progress since September 1988 using this robot. The surface of the building is very complex and therefore presented significant testing conditions for the implementation of robotized operation. This paper gives an outline of the painting robot and describes a number of new experiences and the measures implemented to cope with them during the actual execution of the work.

1. HISTORY OF DEVELOPMENT

At present, this second prototype is in operation, and the site chosen for this test was the Shinjuku Center Building, one of Japan's high-rise buildings. It is a prominent 54-storey building completed in 1979. There are also 5 storeys underground and the total height is 220 m.

The exterior walls are precast resin concrete panels with an acrylic urethane coating. The total area to be painted excluding glass was 47,700 m^2 (including 7,000 m^2 on the inner surfaces of guide rails). The robot applied both an undercoat and a finish coat so the total sprayed area was 95,400 m^2.

As shown in Photo 1, the wall surface of the building is very complex, which complicated the plan for painting using the robot.

2. OVERALL COMPOSITION

2.1 Features of the System

The main features of this exterior wall painting robot are listed below:

a. The construction is such that no paint mist whatsoever escapes into the surroundings.
b. The mechanism leaves no unpainted spots on complicated wall textures (the gaps between courses of masonry work).
c. The density and distribution of paint can be planned and coordinated.
d. The maximum painting rate is more than 100 m^2/hr.

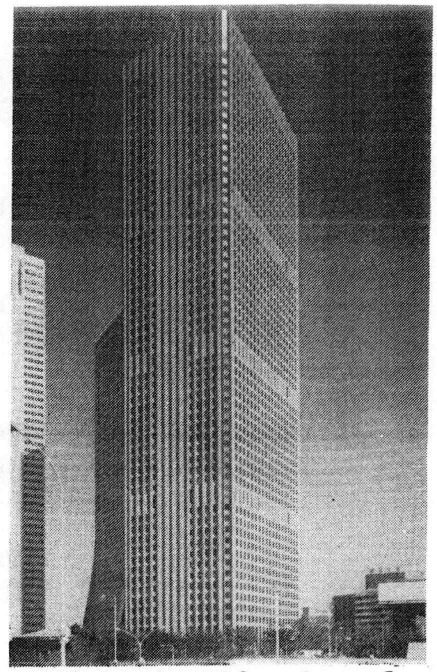


Photo 1 Side view of building

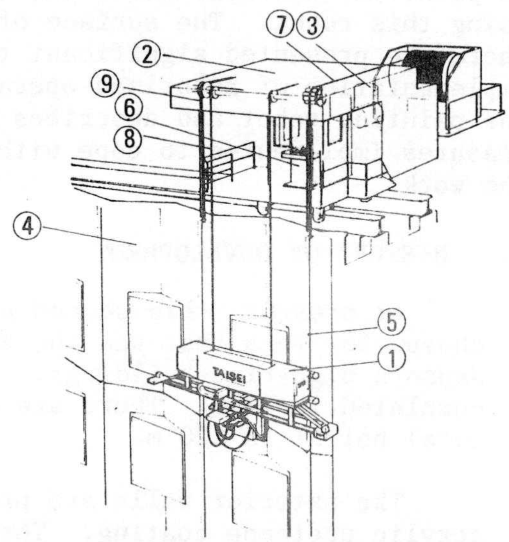
2.2 System Configuration

The system can be roughly divided into 3 blocks. These are the sections of the robot that operates the spray gun and coats the walls, the travelling roof-mounted section from which the robot is suspended and moved up and down by cables, and finally the paint section that supplies paint to the robot.

The paint section is on the roof-mounted unit and supplies paint through a high-pressure hose. (Refer to Fig. 1 and Table 1.)

Table 1 Specifications of Component Devices

	Items	Specifications
Rooftop Section	Travelling section	Lifting load: 1.5 tons Descent speed: 8 m/min Ascent speed: 16 m/min Power consumption: 7.5 kw(400V) (winch)
	Painting devices Paint tanks Paint Pump Compressor	Power consumption: 6.0 kw (200V) 80-liter x 2 13 liters/min max 5 HP
Robot Section	Overall dimensions	5m x 1.6m x 2.0m (LxWxH) Power consumption: 5 kw (200V)
	Weight	1.4 tons
	Devices Compressor Control devices	750 w (200V) programmable controller (for NC control) Up/down movement distance sensor Wall joint sensor Wall surface sensor
	Safety devices	Automatic release of carrier lock Receptacle for emergency power supply
	Hood Painting capability Spray guns	750mm x 600mm (WxH) 100m²/hr 8 Airless-type guns



①. Robot section
②. Traveling roof-mounted
③. Paint section
④. Surface to be painted
⑤. Guide rail
⑥. Monitoring panel
⑦. Paint hose
⑧. Cable
⑨. Power and signal cables

Fig. 1 System Composition

a. Robot section

This section can be further divided into the carrier to which devices are mounted, and a hood beneath it which moves to the right and left on a rail.

A control panel, a compressor to drive the spray guns and air actuator, and a tank for excess paint (collected by recovering paint adhering to the inside of the hood) are mounted on the carrier. The carrier is fitted with guide rollers so that it can move along guide rails on the building, as well as a device which locks the carrier onto the wall surface to stabilize the robot during painting.

There are four drives on the operational part of this section: a motor to move the hood (within which the spray guns are mounted) right and left, another to move it forward and backward, a motor which keeps the hood perpendicular to the wall surface, and a motor which moves the spray guns right and left.

A total of eight spray guns are fitted inside the hood which prevents the scattering of paint mist. They are grouped into pairs, and each pair is adjusted to spray the same area from different angles, eliminating unpainted spots on even the most irregular of textures. (Refer to Figs 2)

Since the hood come into close contact with the wall surface during painting, a pad which adjusts to the irregularities of the wall is attached to the top edge of the hood.

b. Traveling roof-mounted section

The travelling section on top of the building lowers the robot on two cables and adjusts its vertical position. Winches are fitted to wind the cables up and down as well as a reel to take up the cable for electric power, and a monitoring panel which reports any malfunction of the robot to the operator and which serves as a remote control unit (see Photo 2). The vehicle moves on rails laid along the rooftop parapet.

c. Paint supply section

This consists of a paint pump, paint tanks (for primer and overcoat), a compressor to drive the pump, and a reel to wind up the paint hose. The paint pump is a lightweight airless type which greatly reduces the dispersion of paint mist.

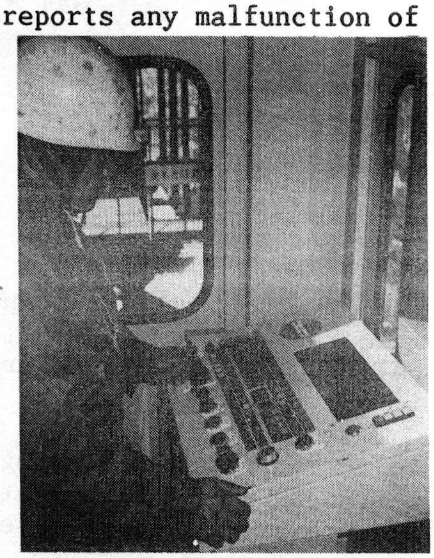


Photo 2 Monitoring Panel in Travelling Section

2.3 Measures to Prevent Paint Scattering

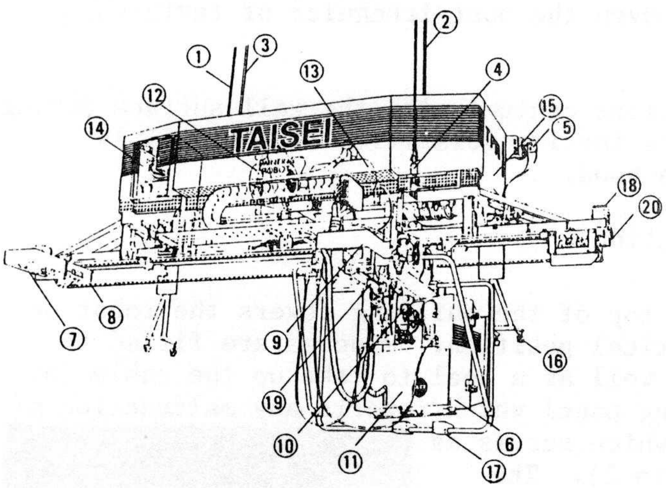
In adopting the spray method of painting, the most important problem to be solved was the prevention of paint scattering.

The solution to this problem was to paint using spray guns inside the hood while a solvent-resistant pad with enough flexibility to fill the irregularities is compressed against the wall for a few seconds by the hood opening. The marks caused by the pressure of the pad on the coated surface are minimized by adjusting the configuration of the pad and the pressure applied.

3. SUMMARY OF CONTROL SYSTEM

Two programmable controllers maintain control over the robot, one mounted on the robot itself and the second in the monitoring panel on the building roof.

The analysis of signals from each sensor on the robot unit and control of the servo system is handled by the control system on the robot while overall control of the system is by the monitoring panel on the roof. Signals between the two controllers are multiplexed to reduce the top of the building wiring needed. Load cells send signals to stop the robot ascending and descending. These signals are sent through an exclusive cable to reduce the response time.(1), (2)



1. Cable
2. Paint hose
3. Power and signal cable
4. Load sell
5. Locking onto wall
6. Printing hood
7. Motor to drive hood
8. Chain drive for hood
9. Motor to drive hood forward and hardware
10. Air actuator to oscillate hood
11. Motor to turn spray guns
12. Air compressor
13. Compressed air tank
14. Sequencer and servo-controller
15. Up/down movement sensor
16. Wall joint sensor
17. Wall surface sensor
18. Socket for emergency power supply
19. Motor for emergency hood withdrawal
20. Socket for emergency air supply

Fig. 2 Detail of Robot Section

4. SAFETY AND EMERGENCY MEASURES

The fail-safe principle has been applied to the machine in the areas of emergency rescue, the movements of the lowering system, the paint hose, signals, power cables, etc.

The total area to be painted on the test building is 95,400 m^2 and to accomplish the painting 4 degrees of freedom are controlled; linear motion in 3 axes and rotation about 1 axis. The 8 sets of spray guns also rotate, making the selection of a drive system the sensors, etc., important considerations. Also, since the work takes place in the open, the equipment was selected in consideration of its temperature, humidity, dust, noise, and vibration limitations.

The main safety and emergency precautions are shown in Table 2.

Table 2 List of major safety and emergency measures

	Nomenclature	No. of sets	Objective
Safety measures	1. Load cell for wire cable	2	In case abnormal tensions are caused on cable, hose, etc. during up/down movement of robot, the robot is stopped for emergency.
	2. Load cell for cable	1	
	3. Load cell for signal cable	1	
	4. Load cell for paint hose	1	
	5. Overflow sensor in hood	1	Detects quantity of paint recovered in recovery tank.
	6. Overflow sensor in tank	2	
	7. Blocking detection sensor for spray gun	8	Detects blocking of spray guns and stops operation.
	8. Paint pressure detection sensor	1	In case quantity of paint supply suddenly changes, cuts off paint line and stops operation.
	9. Paint tank lower limit detection sensor	2	Detects remaining quantity of paint in tank and gives out an alarm
Emergency measures	1. Motor for hood recession	1	Used when abnormal movements are detected in forward/backward motor for hood.
	2. Receptacle for power supply	2	In case abnormalities are caused in power, supplies power from the robot side.
	3. Receptacle for air supply	2	In case abnormalities are caused on locking device, supplies air from the robot side.

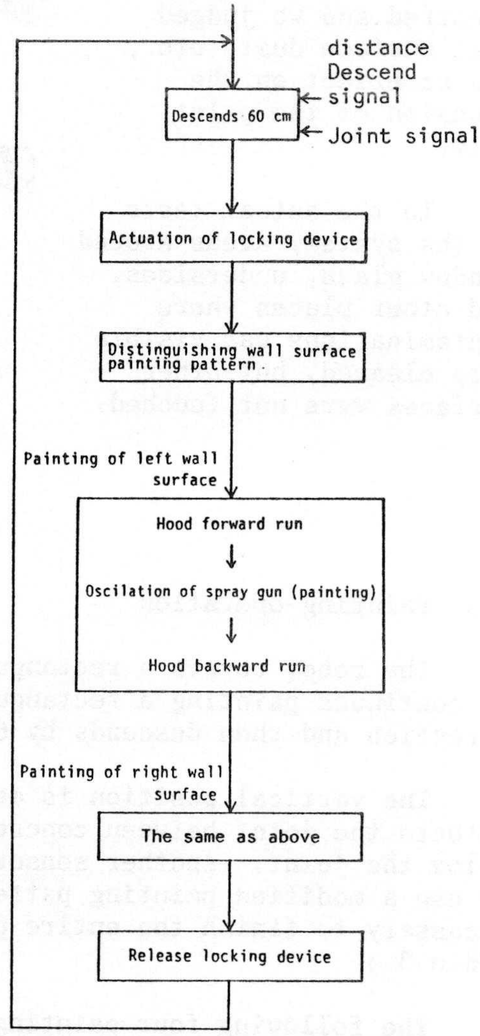


Fig. 3 Automatic Painting Operation Flow

5. PAINTING OPERATION

6.1 Quality of Painted Surface

This robot is designed to paint patterned stone masonry with surface irregularities which would need triple coating for evenness and to eliminate unpainted spots if painted manually. Since the robot constantly supplies paint and repeats its movements, paint is applied and distributed evenly. By the application of one undercoat of sealant which serves as a surface preparation and two finishing coats, an even and uniform film is assured.

Moreover, an even surface is ensured mechanically as painting takes place within the enclosed hood, protecting the painted surface from wind.

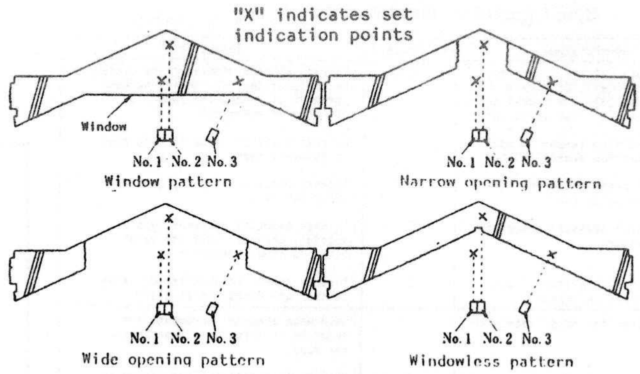
The paint film thickness is controlled by monitoring the amount of paint applied.(3)

5.2 Surface Preparation of Wall

We thought it may be possible to achieve sufficient adhesion when spraying directly onto old paint without removing loose material and cleaning as is ordinarily done. To check this, tests of adhesion after automatic spraying were carried out.

The results showed that no peeling of the new paint from the old occurred and we judged that surface dust, etc., had no effect on the adhesion of the paint film.

In the actual tests of the system, areas around window glass, undersides, and other places where contaminations was visible were cleaned, but other surfaces were not touched.



Section of Exterior Wall

Sensor No. / Pattern	No. 1	No. 2	No. 3
Window pattern	ON	ON	-
Wide opening pattern	OFF	OFF	OFF
Narrow opening pattern	OFF	OFF	ON
Windowless pattern	OFF	OFF	ON

Fig. 4 Wall sensor states for each painting pattern

5.3 Painting operation

The robot covers a rectangular area 75cm x 60cm in a single run. It continues painting a rectangular strip 60 cm deep in the horizontal direction and then descends by 60 cm, repeating the same operation.

The vertical position is detected in two steps: the robot first detects the joint between concrete panels and then senses the distance below the joint. Another sensor detects windows and instructs the robot to use a modified painting pattern. A total of 120,000 such steps are necessary to finish the entire painting operation. (See Fig. 3 and Photo 3.)

The following four painting patterns are used: "window pattern," "wide opening pattern," "narrow opening pattern" and "windowless pattern." The pattern choice is made by analyzing signals from six wall sensors (ultrasonic distance switches) installed on and under the paint hood. Following this decision, the forward/backward and left/right servos operate according to the instructions for each painting pattern and the hood is pressed into close contact with the wall surface below spraying begins. (See Fig. 4.)(4)

5.4 Painting Efficiency

The painting operation commenced in September 1988 and is scheduled to last 9 months in total. The painting team consists of an operator, one person to supply and control the paint, and one person to act as lookout on the ground, making a total of 3 persons. The operator locates robot in the guide rail on the wall to be painted and simply pushes the automatic operation button, requiring no special skills.

Although the robot is capable of painting 100 m²/hr, inspection of the equipment before and after use, trial spraying, location, recovery, and cleaning of the robot takes one hour so the plan is to complete one span per day (550 m²). (See Fig. 5.) Maintenance is carried out after every 200 hours of operation.

Photo 3 Robot in Operation

When comparing efficiency of the robot and manual painting using a gondola, calculations show that the robot takes 30% less time with a 74% reduction in work force. Thus not only time, but a comprehensive cost reduction is achieved in repainting. (See Table 3)

5.5 Results of Application

The various problems which were initially of concern, such as paint scattering, marks on the surface as a result of hood contact, the balance of the robot, and others were satisfactorily overcome as a result of tests performed on the ground. We proved that a large reduction of painting time and a saving of labor could be achieved compared with manual painting.

Since high-rise building with a height of 220 m are subject to violent changes in wind velocity direction caused by structure, painting has to be suspended in strong winds in excess of 12 m/s although the construction of the robot is adequate. Intricate areas, such as between beams and the roof, under surface, the penthouse, etc., have to be painted by hand.

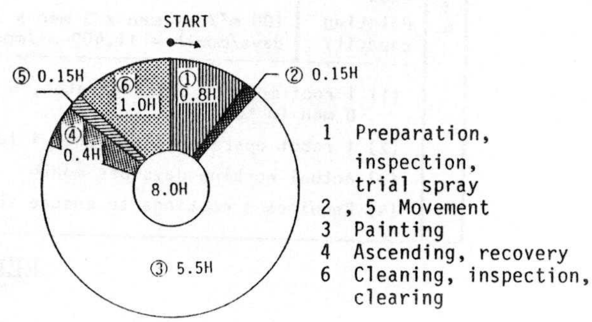


Fig. 5 Average Cycle by Type of Operation/Day

The amount of paint that rebounded into the paint hood and which was recovered using a pump amounted to about 20% of the quantity sprayed.

The robot was designed specifically for use on this building, and we judged that it would be rather uneconomical to convert it for use on other buildings. However, the expertise acquired through work in this case can be usefully applied in future development of the system.

6. CONCLUSION

Thus far, we have described our experience in putting the painting robot for external walls of high-rise buildings into operation.

The most important tasks in the development and application of this robot included resolving previously unanswered questions such as how the ideal movements of a spray gun operated by a skilled worker could be simulated mechanically, how to prevent the dispersion of paint, secure the paint film thickness on complicated wall textures, how to apply the paint etc.

We hope that this report will be of help to others who are engaged in similar studies.

Table 3 Comparison of Manual and Robot Painting

		Conventional method (3 gondolas)	Robot method (1 set)
Construction schedule (month)		1 5 10 13 13 months	1 5 9 (Reduction by 30%) 9 months
Labor (men)		1,000 2,000 1,976 men	500 (Reduction by 74%) 513 men
Remarks	Men per month	(1) 8 men x 19 days/month = 152 men/month	(2) (3) 3 men x 19 days/month = 57 men/month
	Total men	152 men/month x 13 months = 1,976 men	57 men x 9 months = 513 men
	No. of coating	1 undercoating, 2 final coating, 3 coats in total(4)	1 undercoating, 1 final coating, 2 coats in total
	Total painting area	143,100 m^2	95,400 m^2
	Painting capacity	100 m^2/day.man x 3 men x 19 days/month = 11,400 m^2/month	550 m^2/day x 1 set x 19 days/month = 10,450 m^2/month

(1) 1 roof-mounted unit operator, 6 painters, 1 lookout on ground. 8 men in total

(2) 1 robot operator, 1 mixing, 1 lookout on ground. 3 men in total

(3) Actual working days per month

(4) Requires 3 coatings to ensure the paint film thickness

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