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DEVELOPMENT OF WALL COATING REMOVAL ROBOT

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ABSTRACT

We have developed a wall coating removal robot for refurbishing exterior walls of buildings. This robot consists of a base machine, capable of adhering to and travelling freely along wall surfaces by means of suction pad and four wheels, and a rotating water jet nozzle built into the suction pad. The special feature of this robot is that this suction pad can suck up removed materials and water through vacuum hose without scattering them around. Basic tests for evaluating the travelling and removal performance of the robot on two types of wall coating were performed. In addition, a device which provides the robot with a supplementary function of removing wall coating from the peripheral areas of walls was experimentally produced, and some tests were performed on the two types of wall coating mentioned above to assess its removal performance. This report describes the results of these tests and the problems to be solved in the future.

1. INTRODUCTION

In Japan, young people consider the construction industry to be “dirty, hard and dangerous” and they reject becoming construction workers because of this unfavourable image. Consequently, the construction industry is suffering from serious problems of labor shortage, aging and lowering technical standards of workers. As one of the solutions to these problems, we have been developing various types of construction robots. We performed basic tests on a wall coating removal robot and the results of these tests are summarized in this paper. This robot has a water jet nozzle built into the suction pad which provides the robot with a special feature of sucking up all the removed materials and water without scattering any of them around.

2. OUTLINE OF SYSTEM

This robot consists of a base machine, capable of adhering to and travelling freely along wall surfaces by means of suction pad and four wheels, and a rotating water jet nozzle built into the suction pad. The other devices attached to the robot include a vacuum pump, a water jet device, and an auto-tension winch. The outline of the system is shown in Figure 1, the picture of the robot travelling along a wall surface is shown in Photograph 1, and the picture of the water jet nozzle in action is shown in Photograph 2 respectively. The specifications of the components are described in Table 1.

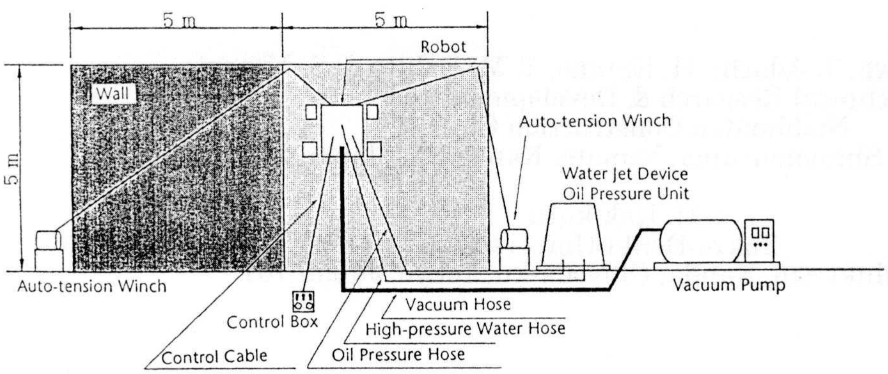
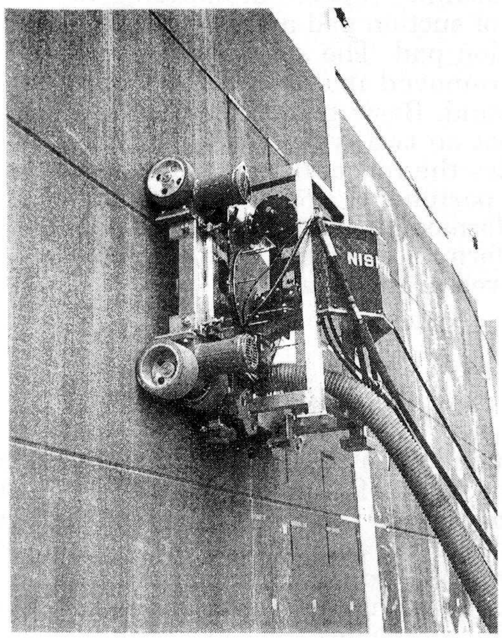
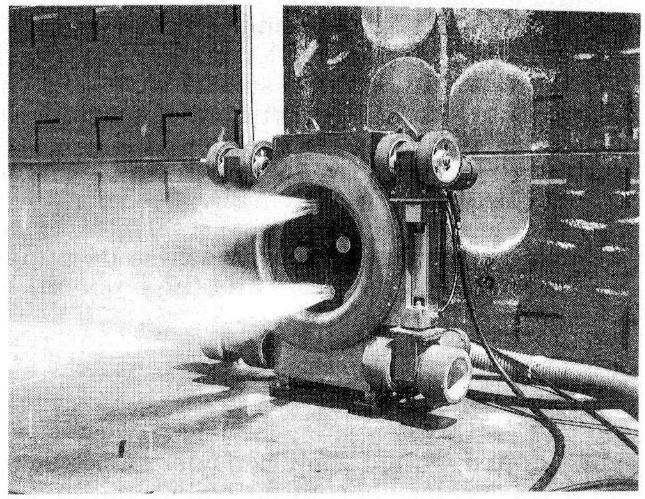


Figure 1 Outline of system





Photograph 2 Water jet nozzle in action

Photograph 1 Robot travelling along a wall surface

Table 1 Specifications of components

Wall Coating Removal Robot	
Travel Speed	Variable, Maximum Speed 9m/min
Suction Force	Approx. 1000kgf
Weight	Approx. 290kgf
Area of the Suction Opening	Less than 1,600mm^2
Geared Motor	0.4kW, u=1/200, Quantity: 4 (u: Reduction Gear Ratio)
Auto-tension Winch	
Rated Rope Pulling Capacity	500kgf
Rope Pulling Capacity during Auto-tension Setting	15 to 20kgf
Motor	1.5kW, 12p
Water Jet Device	
Maximum Injection Pressure	3850 kgf/cm^2
Prime Mover	230hp (Diesel)
Vacuum Pump	
Suction Rate	28m^3/min

3. TRAVELLING PERFORMANCE TEST

It is important to confirm whether differences in the conditions of the travel surfaces result in variation in the travel speed of the robot. A concrete floor and two vertical concrete walls (5m × 5m), one of which was provided with a wall coating for thin textured finishes (hereinafter referred to as "Type 1") and the other with a multi-layer wall coating for glossy finishes (hereinafter referred to as "Type 2"), were prepared for the test. The test was performed by moving the robot in upward, downward and transverse directions under wet and dry conditions of the wall surfaces, using the frequency of the power supplied to the motor (variable: 0 to 95Hz) as a parameter.

The results shown in Figures 2, 3, and 4 indicate that there is little variation in the travel speed of the robot when moving in different directions (upward, downward and transverse) due to differences in the types of coating materials or conditions of the wall surfaces. The speeds vary more or less in proportion to the power supply frequency. In the wet condition, the robot travelling upward along the Type 2 coating surface slipped and stopped when its speed exceeded 5.5m/min (60Hz). When the travel speeds of the robot on the vertical walls are compared to those on the concrete floor, it is observed that the downward speed is slightly greater while the upward and transverse travel speeds are much the same.

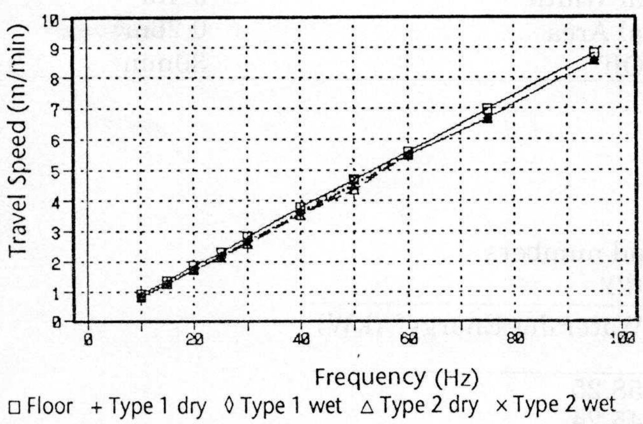


Figure 2 Upward travel speed on wet and dry wall surfaces

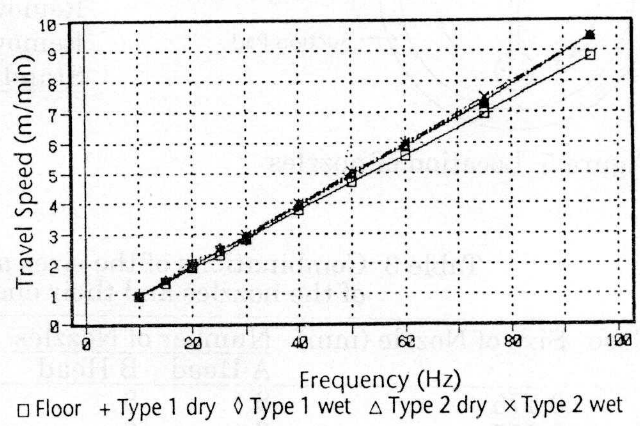


Figure 3 Downward travel speed on wet and dry wall surfaces

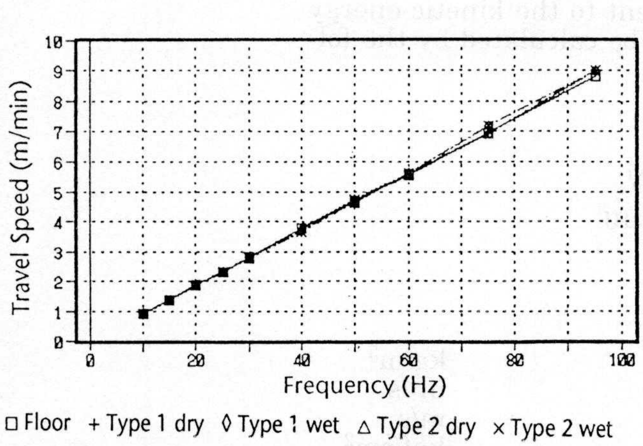


Figure 4 Transverse travel speed on wet and dry wall surfaces

4. REMOVAL PERFORMANCE TEST

Removal performance tests were carried out on two types of coating materials using the sizes and numbers of nozzles and the distance between the nozzle and the wall surface (hereinafter referred to as "stand-off") as parameters.

4.1 Removal performance test using different sizes and numbers of nozzles

The location of the nozzle heads is shown in Figure 5. Each head has eight holes for the installation of the nozzles. The test conditions are shown in Table 2. The combinations of the sizes and numbers of the nozzles used for the experiment and their water jet energy are shown in Table 3.

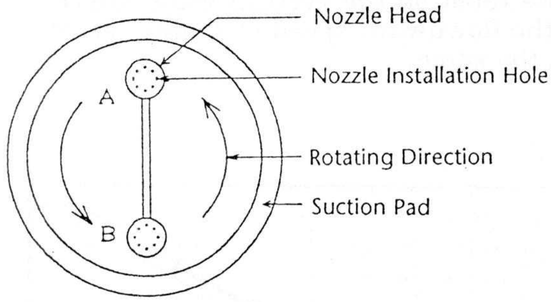


Figure 5 Location of nozzles

Table 2 Test conditions

Injection Pressure of Water Jet Device	3000kgf/cm^2
Rotation Speed of Nozzle Heads	500rpm
Travel Speed	2.2, 5.5m/min
Travelled Distance	0.65m
Removal Width	0.4m
Removal Area	0.26m^2
Stand-Off	30mm

Table 3 Combinations of the sizes and numbers of the nozzles and their energy

Case	Size of Nozzle (mm)	Number of Nozzles A Head	Number of Nozzles B Head	Water Jet Energy* (kW)
1	0.175	8	8	58.25
2	0.175	6	6	45.24
3	0.175	4	4	30.81
4	0.275	3	3	54.43
5	0.275	2	2	37.73
6	0.300	2	2	44.30

* The water jet energy per unit time is equivalent to the kinetic energy per unit time of the water jet flow, which can be calculated by the following formula.

$$E(\mathrm{W}) = \frac{\rho Q V^2}{2}$$

$$Q(\mathrm{m}^3/\mathrm{s}) = 0.7\times 29.8\times\sqrt{14.3\times P_1}\times\left(\frac{d}{25}\right)^2\times 3.785\times\frac{N}{60\times 10^3}$$

$$V(\mathrm{m/s}) = \sqrt{2g(P_1-P_2)\times\frac{10^4}{\rho}}$$

where,

ρ	: Density of water, 1×10^3	kg/m^3
Q	: Water jet flow rate	m^3/s
V	: Water jet velocity at the nozzle outlet	m/s
P_1	: Injection pressure of water jet device	kgf/cm^2
P_2	: Pressure drop calculated from amount of water jet flow rate (Q)	kgf/cm^2
d	: Size of nozzle	mm
N	: Number of nozzles	
g	: 9.8m/s^2	

The removal performance was assessed by visual inspection, grading the test results using a 7-point scale as a standard (see Table 4). On this scale, the optimum value of 5 was given when only the coating materials were completely removed, 1 to 4 when some of the coating materials remained unremoved, and 6 or 7 when some of the concrete surface was shaved off due to excessive removal of the coating materials. The results are shown in Table 5.

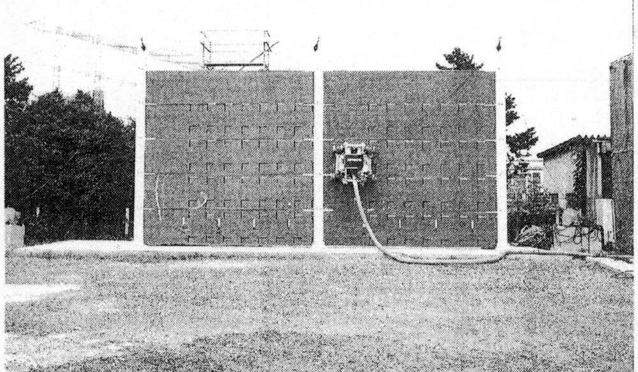
Table 5 shows that both Type 1 and Type 2 coating materials were removed satisfactorily (i.e. the optimum value of 5 was achieved) in Case 1 when the robot travelled at 5.5m/min and in Cases 3, 4 and 5 when the robot travelled at 2.2m/min. The energy applied to the removal area was 407.75kW·s with the robot travelling at 5.5m/min in Case 1, and 554.58kW·s, 979.74kW·s, and 679.14kW·s with the robot travelling at 2.2m/min in Cases 3, 4 and 5 respectively. The coating materials were appropriately removed with the least amount of energy applied to the removal area in Case 1 with the robot travelling at 5.5m/min. Photographs 3 and 4 respectively show the wall surface before and after the removal of the coating materials.

Table 4 Removal assessment standard

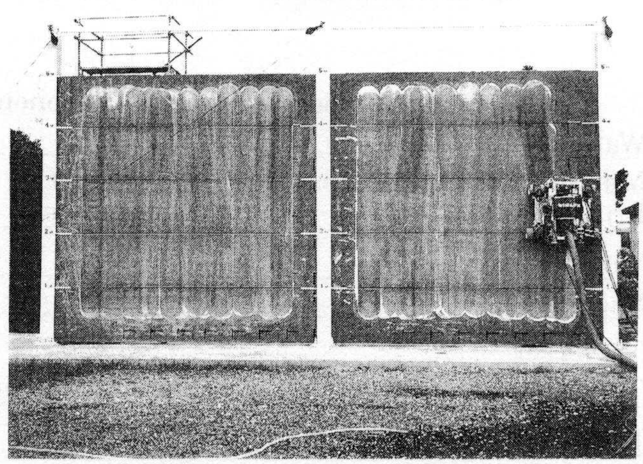
Standard Value	The Removal Rate of Coating Material
1	20%
2	40%
3	60%
4	80%
5	100%
6	105% (Concrete surface removed)
7	110% (Concrete surface removed)

Table 5 Assessment of removal of type 1 and type 2 coating materials

Case	Combination of Nozzles		Travel Speed (m/min)			
	Size (mm)	Number	2.2 (t=18sec)		5.5 (t=7sec)	
			Type 1	Type 2	Type 1	Type 2
1	0.175	16	7	6	5	5
2	0.175	12	6	6	4	4
3	0.175	8	5	5	4	3
4	0.275	6	5	5	4	3
5	0.275	4	5	5	3	1
6	0.300	4	6	6	4	4



Photograph 3 Wall surface before removing coating materials



Photograph 4 Wall surface after removing coating materials

4.2 Removal performance according to stand-off

A removal performance test using the stand-off as a parameter was carried out for each type of coating material. The size and number of nozzles used for this test were the same as those used in Case 1, which proved to be appropriate by the test described above. The test conditions were the same as those shown in Table 2, except for the stand-off. The assessment of the removal performance was performed according to Table 4. The results are shown in Figures 6 and 7.

The results indicate that within the range of stand-off adopted in this test, the removal effect increases as the stand-off decreases. The removal effect below a stand-off of 25mm should also be tested.

5. PERIPHERAL WALL COATING REMOVAL TEST

The tested wall coating removal robot cannot remove the coating materials on the peripheral area of a wall due to its structure. Therefore, we experimentally produced a peripheral wall coating removal device which will be added to the robot as a supplementary function in the future. The removal performance test of this device was performed on two types of coating materials by using the same testing method as described above.

This device, like the robot, has its water jet nozzles installed in the suction pad and sucks up all the removed materials and water by a vacuum pump without any scattering around. It travelled on a moving device called a "traverser" which enabled it to move horizontally and vertically. Figure 8 shows the outline of the peripheral wall coating removal device, Photograph 5 shows the testing scene, and Table 6 shows the specifications of the components respectively.

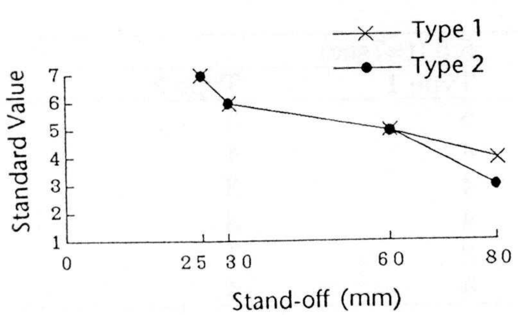


Figure 6 Removal characteristics at travel speed of 2.2m/min

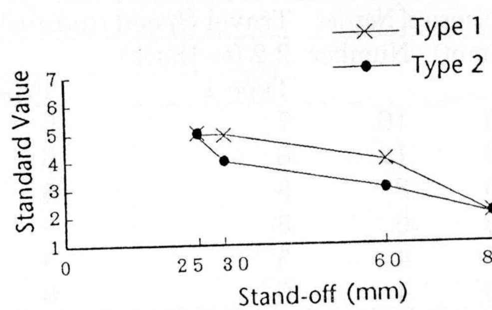


Figure 7 Removal characteristics at travel speed of 5.5m/min

Table 6 Specifications of components

Water Jet Device	
Maximum Injection Pressure	3850kgf/cm^2
Prime Mover	230hp (Diesel)
Vacuum Pump	
Suction Rate	5.0m^3/min
Traverser	
Travel Speed	Variable, Maximum 1.6m/min
Peripheral Wall Coating Removal Device	
Weight	20kgf
Nozzle Head (As same as the robot)	1

The removal performance test of the peripheral wall coating removal device was performed on concrete wall surfaces (height 1m, width 5m, depth 0.1m) coated with the same two types of coating materials, using stand-off and travel speed as parameters. The test conditions are shown in Table 7. The removal performance of the device was assessed by visual inspection in accordance with Table 4. The results are shown in Figures 9, 10 and 11.

The results indicate that, like the forementioned robot, the removal effect increases as the stand-off decreases. There is little difference between the removal effects at a stand-off of 15mm and at that of 20mm, except for when the device is travelling along a Type 1 surface at a speed of 1.0m/min.

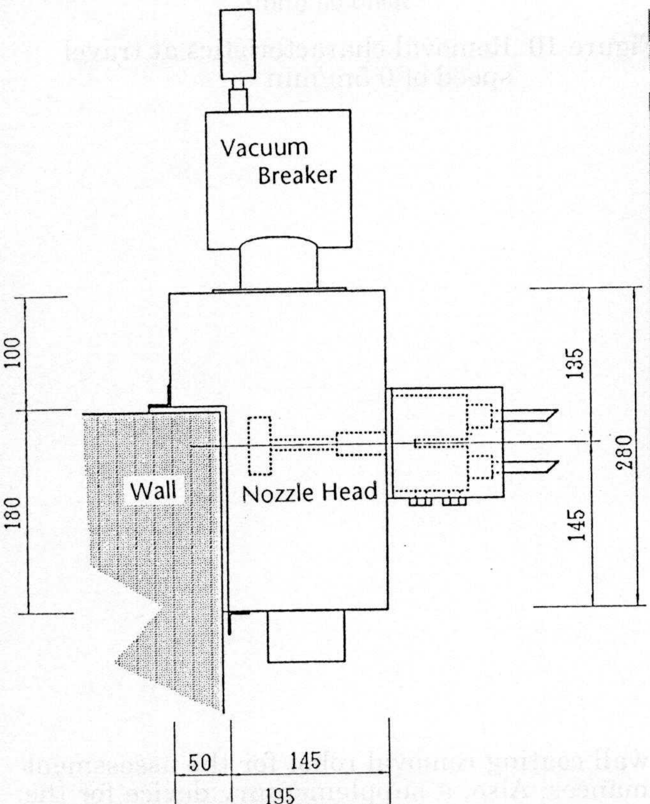
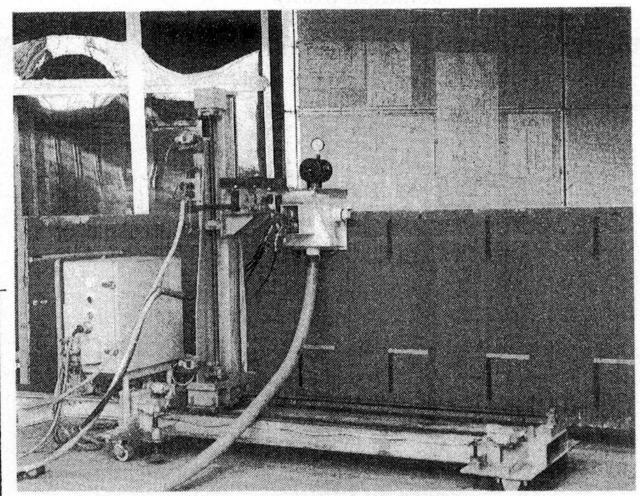


Figure 8 Peripheral wall coating removal device



Photograph 5 Testing scene

Table 7 Test conditions

Rotation Speed of Nozzle Head	500rpm
Size and Number of Nozzles	0.175mm, 8
Injection Pressure of Water Jet Device	2000kgf/cm^2
Travel Speed	0.25, 0.5, 1.0m/min
Travelled Distance	0.3m
Removal Width	5cm
Removal Area	150cm^2
Stand-off	15, 20, 40, 60, 80mm

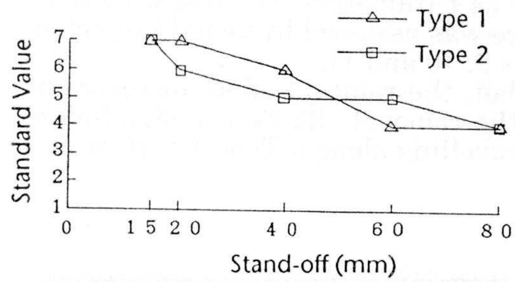


Figure 9 Removal characteristics at travel speed of 1.0m/min

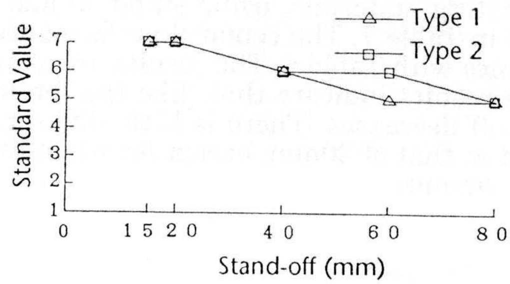


Figure 10 Removal characteristics at travel speed of 0.5m/min

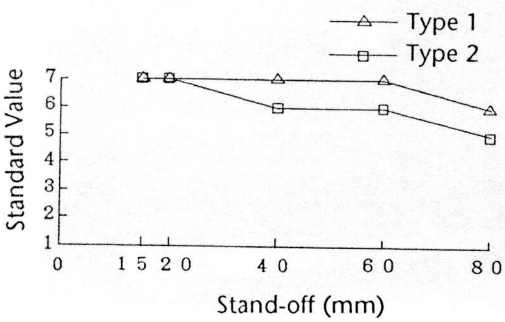


Figure 11 Removal characteristics at travel speed of 0.25m/min

5. CONCLUSION

Fundamental tests were performed on the wall coating removal robot for the assessment of its properties in travelling and removal performances. Also, a supplementary device for the robot to remove the wall coatings in peripheral areas was experimentally produced and its removal performance was confirmed. However, to put this robot to practical use, there are some problems to be solved. For instance, the robot cannot travel on surfaces where there are large gaps or steps. We intend to solve these problems and to install the supplementary peripheral wall device onto the robot. And we will also devise adding some automatic navigation and removal functions to the robot in the future.

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