Development and Implementation of Troweling Robot for Concrete Floor Finishing

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Abstract

In the construction industry, concrete floor finishing is hard and laborious, and the number of skilled plasterers has dropped sharply. Due to these circumstances, several types of robots were developed to meet the need. But they have not spread too widely. Understanding the problems of these robots, we developed a new type of robot from the view point of robotized "tool". It is a compact and light-weight robot of simple operation which can be operated even by unskilled workers. In addition,it can be used from an early stage of work, or the beginning of concrete's setting, which is difficult with conventional robots. This paper describes the background of our development, its design concept, its mechanism and motion and the result of trial operations at actual construction sites and our future prospect.

1. Introduction

The smoothing of a concrete floor is a laborious task which is to be executed in a hunched position, synchronixed with the setting of concrete. In addtion, at which timing to start the work entirely depends on the "intuition" of a skilled plasterer. In summer the work must be done in a short time while in winter it needs to be done slowly for many hours, from midnight to the next morning. Therefore the work mostly depends on the hands of skilled and experienced plasterers. However, the number of plasterers has decreased sharply : from approximately 230 thousand in their golden days to approximately 50 thousand today. To overcome the shortage of labor, the industry has long desired to develop and introduce a labor-saving, automatized machine. And till now several types of concrete floor finishing robots have been developed in Japan. To widely apply these robots, some problems must be solved.

2. Concept of the robot

2.1 Prior investigation

a) Currently used robots

Before starting the development, we re-examined what ploblems needed to be solved by inquiring the opinion of plasterers, related organizations and collecting related papers. As a result, we recognized the following problems with currently used concrete floor finishing robots:

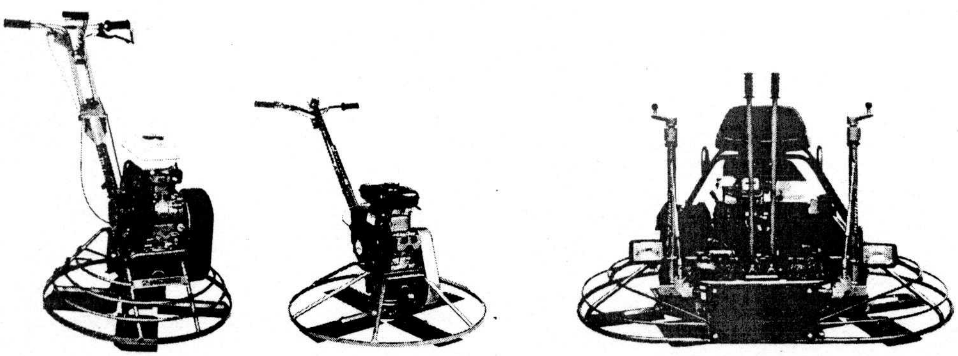
- Due to their heavy weight, it is quite hard to carry a robot in/out of a site or to move it in a site.

- Troublesome set-up work before and after placing concrete, such as connection and removal of the power cable.
- The sites where the robot can be used are limited, resulting in a low operation rate.
- Too expensive compared with conventional troweling machines

b) Currently used troweling machines

Today power trowels are most frequently used at sites as concrete floor finishing machines (see Figure 1). There are two types of power trowels: hand truck type and mobile boarding type. The former is more widely spread. The reasons are:

- They can cope with a wide range of work: from smoothing with wooden trowel to finishing with metallic trowel.
- Various (from small to large) sizes of machines are prepared so as to choose the most suitable one for any object site.
- Low cost



hand truck type　　　　　　　　mobile boarding type

Figure 1 Power trowel

2.2 Cocept formation

After clarifying the present situation of floor finish troweling robots, we proceeded to concept formation and determined specifications for the robot to be developed.

a) Movement and transportation

In construction sites, the finishing of floor concrete is a one day job or so, except for very wide floors. Because plastarers move from site to site every day, the robot used in this work needs to be light enough and so constructed that it can be transported by plasterers and easily be carried upstairs with a cargo lift available at site or manually by several plasterers, like machine trowels. Such portability will greatly expands the coverage of the robot.

b) Working range

Due to the restriction from ground pressure, the existing robots can be used only after the setting of concrete has progressed to a large extent. In conventional work schedules, they can be used only in the latter half stage of smoothing and finishing with metallic trowels. Actual work includes the former half stage of smoothing with wooden and metalic trowels, which are to be done while concrete is still soft. To expand its working range, the robot should be able to cope with these works, also.

c) Trowel and traveling method

With trowel rotating methods, the trowel's moving direction tends to be different from the robot's running direction, which causes the edge of the trowel to leave a spiral mark that does not have a bad influence on the accuracy of the concrete surface but degrades the appearance. To solve this problem, we decided to employ a "reciprocating trowel" which moves like the hand of a plasterer.
By vibrating the trowel at ultrasonic frequency, running resistance can be reduced, and the robot can be made small.

d) Level of automation

Because highly automated robot seems to result in larger size, heavier weight and higher cost, we did not aim at a highly automated robot from the beginning but decided to increase the level of automation in harmony with the robot's spreading in the field, taking the opinion of field workers into consideration.

Defining the robot as a compact and light-weight "tool" for plasterers, we formed the following concept for the robot.

- Split and assemble type to ease movement and transportation
- Long ultrasonic trowels arranged at the front and the rear of travel gear, the robot travels to-and-fro.
- The robot covers the works from smoothing with wooden trowel to finishing with metalic trowel.
- Engine generator is used as the power source to achieve autonomous travel.
- The robot can be moved by simple remote operation.

The figures below show the conceptual drawing of the robot, and which plastering works are to be covered by the robot (see Figure 2, 3).

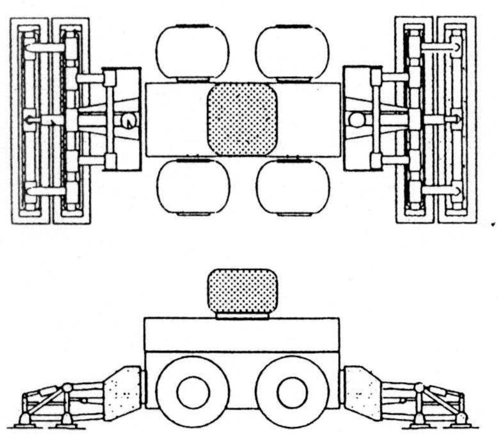


Figure 2 Conceptual drawing of robot

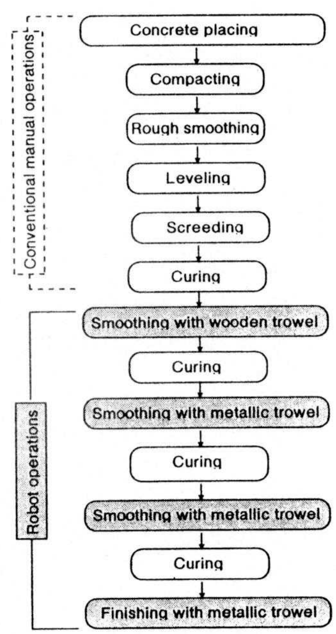


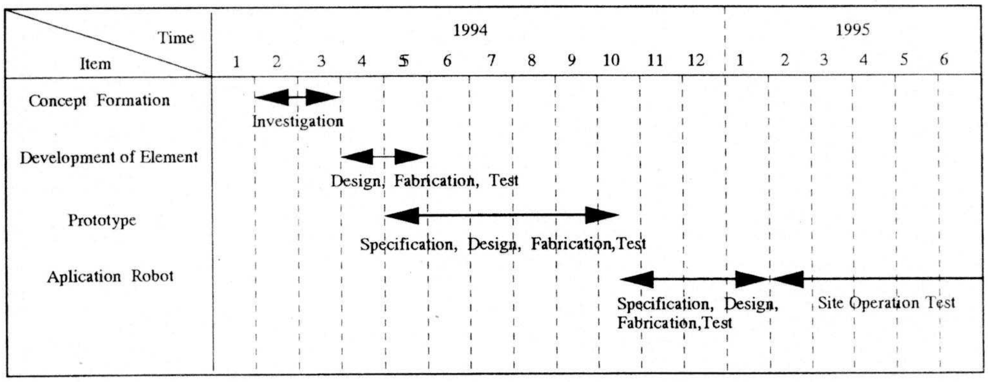
Figure 3 Plastering works covered by the robot

3. Development history

3.1 Development history

The table 1 shows the development history since 1994.

Table 1 The development history



3.2 Development of Elementary Techniques

a) Performance test of ultrasonic trowel

Operation test of ultrasonic trowel was performed on a trowel test stand (see Figure 4). The test revealed that the following conditions must be satisfied to achieve excellent smoothing and finishing operations.

Trowel setting angle: 2 to 5 degree
Trowel pressing force:
4 kgf for wooden trowel
10 kgf for metallic trowel
Traveling speed: 15 to 30 cm/s
Tractive force: 5 to 10 kgf

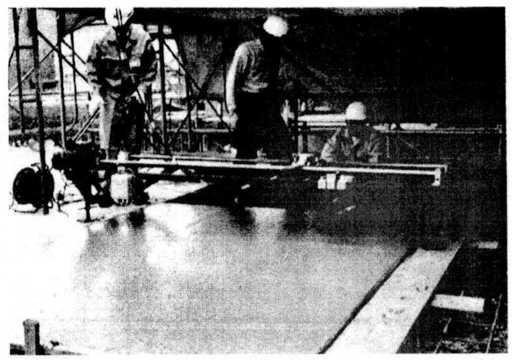


Figure 4 Operation test of ultrasonic trowel

b) Selection of undercarriage travel gear

Running performance was compared between two types of travel gear: rubber caterpillar type and low-pressure membrane tire type. The test showed no significant difference in tractive force between them. Therefore, we determined to employ the latter(low-pressure membrane tire type) which excels the former in maintainability (see Figure 5,6).

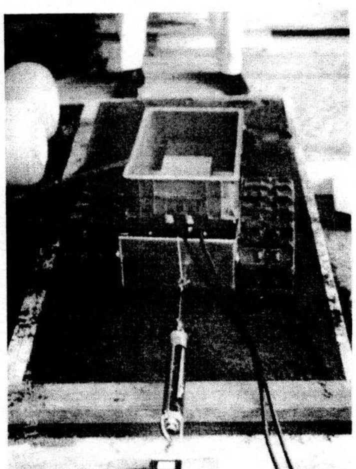


Figure 5 Running test (rubber caterpillar)

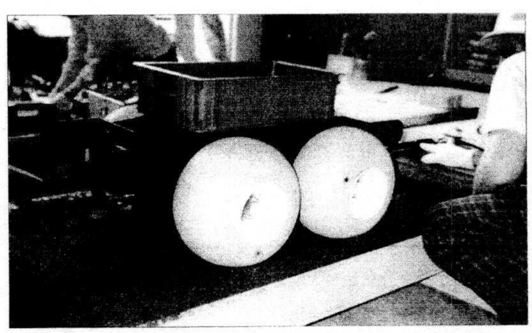


Figure 6 Running test (low-pressure membrane tire)

c) Manufacture of prototype

We manufactured a prototype based on the results of above tests.

- Because the robot travels to-and-fro, the same trowel units are mounted at the front and the rear of the travel gear. They consist of the finishing ultrasonic trowel of horizontal vibration mode(arranged outside) and the leveling ultrasonic trowel of vertical vibration mode (arranged inside).
- A vibro-plate is arranged between inside trowel and travel gear to promote purging bubbles and letting whitewash come up to the surface (see Figure 7).

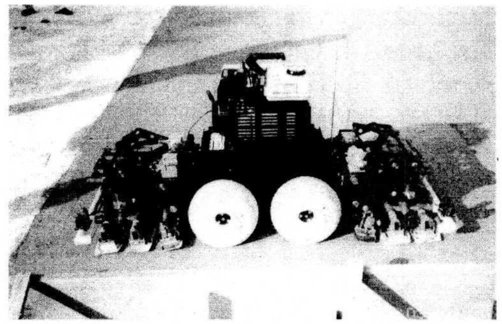


Figure 7 Appearance of prototype model

Operation test with the prototype was performed to check its basic performance (capacity, accuracy, safety). The test revealed the following problems:

- Target capacity (300m^2/h) cannot be achieved due to too slow traveling speed.
- When the robot changes its running direction and the trowels are reversed, trowel marks are left on the concrete surface.
- It takes a considerably long time to stop the robot after the safety bumper has come in contact with an obstacle, disturbing the reinforcing bars which have come in contact with the bumper.

4. Outline of the Application Robot

We thoroughly investigated the problems of the prototype to make an improvement and developed an application robot, the appearance of which is shown in Figure 8. Features of the application robot are as follows:

- The robot is divided into 6 units (travel gear, front and rear trowel units, power unit, control unit and radio control unit for remote operation) which can be carried and assembled by hand. The assembled robot can be moved or transported by a light van (see Figure 9). The drive mechanism of the travel gear and the front and rear trowel units are actuated independently by a small moter. A total 10 moters are used, the maximum weight of which is 1.4 kgf.

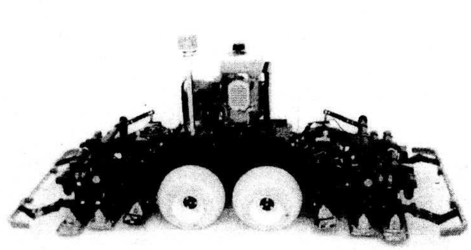


Figure 8 Appearance of Application Robot

Figure 9 Robot loaded on a light van

- To reduce weight, we developed a new high-frequency generator which is only 15 kgf heavy but can develop as high as 700 W power.
- The frame is made of aluminum alloy. Also for trowel supporting pipe, light-weight, high-strength material (steel pipe with vinyl coating) was used.
- The trowel mounting section is of "pantograph" construction so that trowels always comes in contact with the concrete surface at a constant angle, independent of the vertical movement of the mounting section while the robot is traveling.
- To solve the problem of trowel marks being left on the concrete surface when trowels are reversed after the robot has reached the end point of travel, the mechanism is to lift and lower the entire trowel unit and automatically adjust trowel setting angle according to running direction (see Figure 10, 11).

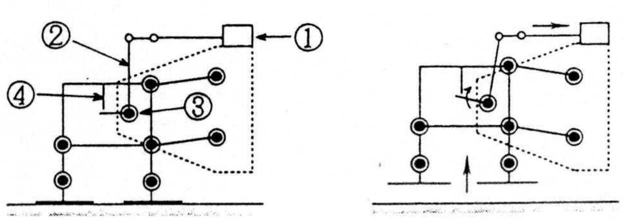


Figure 10 Trowel Lifting Mechanism

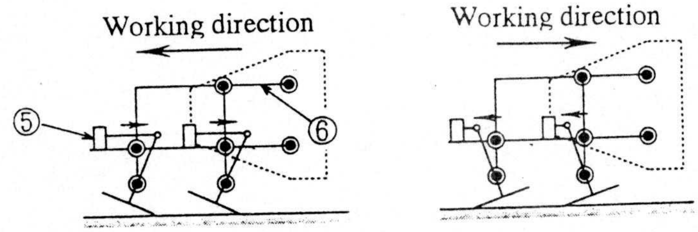


Figure 11 Ajustment of Trowel Angle

- The safety bumper is improved to have a buffering area which effectively absorbs, by telescopic action, the travel under inertia force until the robot stops after the bumper's come in contact with an obstacle (the overrun until the robot completely stops after STOP signal has been output).
- The robot has two operation modes: remote control by radio control and automatic operation with learning function. Figure 12 shows the entire signal circuit.

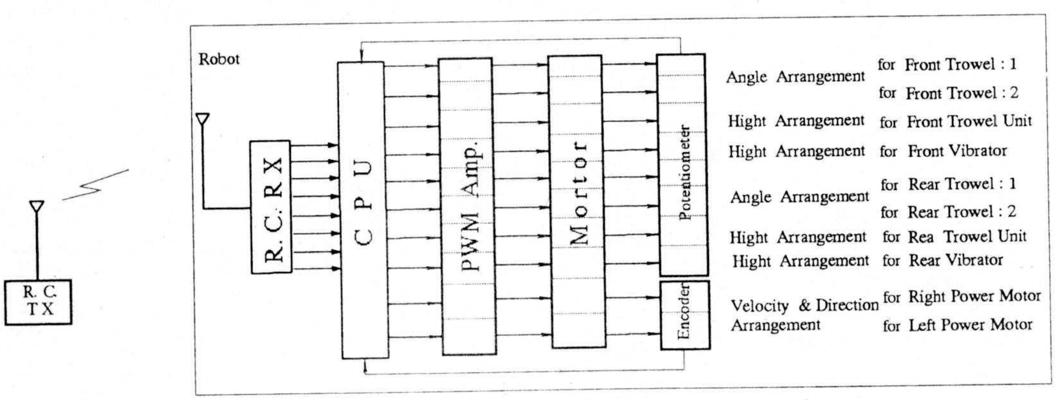


Figure 12 Signal circuit diagram

We made a 7 m x 7 m large test field which models a small construction site. In the test field, the application robot underwent operation tests to check the capacity, accuracy and noise level. The test revealed that the robot achieves all our targets. Tables 2 to 4 show the measurement of capacity, accuracy and noise level. The test also revealed that the safety bumper works correctly.

Table 2 Capacity of robot

Work Content	Operation Size	Operation Time	Operation Ability
Smoothing with wooden trowel	49m^3	9 min 57 sec	295 m^3/h
Smoothing with metallic trowel(1st)	49m^3	8 min 50 sec	333 m^3/h
Smoothing with metallic trowel(2nd)	49m^3	9 min 02 sec	325 m^3/h
Average	49m^3	9 min 16 sec	317 m^3/h

Table 3 Working accuracy of robot

unit:mm

Mesirement Position	Average	Standard Deviation
I	1.0	0.63561
II	0.5	0.33628
III	0.7	0.49714
IV	1.0	0.58604
V	0.6	0.53362
VI	0.5	0.45895
VII	0.8	0.49766
VIII	0.9	0.60169
IX	0.7	0.50697
Average of all / Average	0.7	0.54998

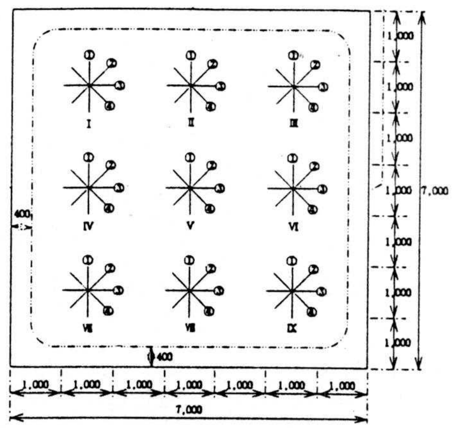


Figure 13 Measuring points of working accuracy

Table 4 Noise Level

unit:dB(A)

Distance from Robot		7m	15m	30m
Smoothing with metallic trowel, using engine generator	Front	69.5	62.0	49.0
	Left	70.0	60.0	51.0
	Rear	74.0	66.0	53.0
	Right	72.0	65.0	53.0
Average		71.4	63.3	51.5

Precision noisemeter : NL-14 from RION Co.Ltd.

5. Result of Operation at Actual Sites

The robot underwent operation tests at 5 actual construction sites, working a total of 1,000m^2 of concrete.

Figures 14 and 15 show the state of operation test at actual construction sites.

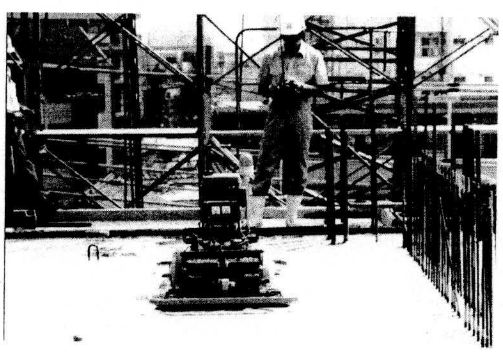


Figure 14 Operation at an actual site

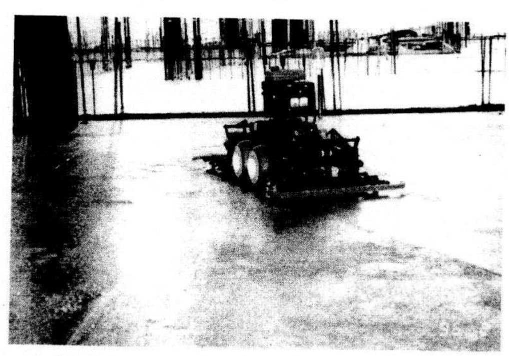


Figure 15 Operation at an actual site

Thanks to redused weight devices, the total weight of the robot is reduced to only 73 kgf, and even the heaviest one of the disassembled units is only 23 kgf.
Ground pressure of the robot is approximately 0.1 kgf/cm², which is almost the same as that of a plasterer wearing "snowshoes". An operation test at a site revealed that the robot can be employed in work in an earlier stage than a plasterer because the front and rear edges of "snow-shoes" flaws concrete surfaces. In the operation test at actual sites, the robot was valued fairly well but, at the same time, the followi ng problems were pointed out.

a) Traveling performance of the robot

- In smoothing with wooden trowel, if the robot is introduced too early, it tends to slip, making directional control difficult; if introduced too late, whitewash hardly comes up to the surface. Both result in poor finishing. Similar problems occur when the setting of placed concrete differs partly due to sunlight.
- In smoothness, a surface finished by the robot is almost the same as that finished manually by plasterers. But the robot sometimes leaves the print of tires when suddenly changing direction.

b) Final finishing with metallic trowel

Cement paste sticks to the tires, partly leaving the print of tires on the concrete's surface. The print of tires is difficult to remove by finish troweling.

Many of these problems depend on the experience and skill of the operator and seem to be solvable through practice. As supplementary measures, we would like to provide guidance in the operation method and to improve the operation manual.

6. Afterword

Concerning compactness, light-weight, easy operation and the quality of work, our robot succeeded fairly well and was awarded the 1995 Valuable Construction Tecnology Award.
Considering that the horizontal accuracy of finished concrete surface mainly depends on the leveling work of plasterers and screeding just after concrete placing and that the robot cannot work in the vicinity of columns and molds, the floor finish-troweling robot is tool which requires the cooperation of plasterers to recover its slight nonconformities.

To achieve the target "easy operation for anyone", we will continue to make improvements, such as non-slip travel, elimination of tire marks.
We will be grateful if the development of the robot leads to the improvement of the working environment and the creation of a new construction method.