Automation and Robotics in Construction X
G.H. Watson, R.L. Tucker and J.K. Walters (Editors)

Development of an Exterior Wall Painting Robot Capable of Painting Walls with Indentations and Protrusions

Shin Terauchi (a), Toshikazu Miyajima (b), Takezo Miyamoto (c), Kazuhiko Arai (d) and Seiichiro Takizawa (e)

(a) Kajima Corporation, No. 4 Research Division 2-19-1 Tobitakyu, Chofu Tokyo, Japan
(b) Kajima Corporation, No. 7 Research Division 2-19-1 Tobitakyu, Chofu Tokyo, Japan
(c) Kajima Corporation, Construction Business Headquarters, Machines Division 1-1-5 Fujikage Bldg., Motoakasaka, Minato-ku, Tokyo, Japan
(d) Kajima Corporation, Construction Business Headquarters, Construction Engineering Headquarters, Production Engineering Division 1-2-7, Motoakasaka, Minato-ku, Tokyo, Japan
(e) Kajima Mechatronics Engineering Co., Ltd. 1-6-1 Minamidai, Kawagoe, Saitama, Japan

Abstract

We developed an exterior wall painting robot for the purpose of automating this painting operation. The robot is mounted on equipment which permits it to move up and down, left and right along the exterior walls of a building. It is computer controlled and is activated simply by the operator pressing a switch on the control panel located on the ground. The robot is capable of painting a four square meter wall surface (4 m long × 1 m high) at one time. It is also equipped with sensors which measure indentations and protrusions in the wall surface, making it possible for it to paint exterior walls with windows, pillars or other indentations or protrusions.

1. Introduction

In recent years, the construction industry has experienced the effects of an aging work force, including a chronic shortage of skilled construction workers. This has resulted in a tendency for work efficiency and quality to deteriorate. One method of overcoming this problem that has been urged forcefully upon us has been automation and robotization of construction operations. One of the areas where this has been attempted is in painting work using the painting robot.

2. Robot Development Concepts

This robot was developed to meet the following requirements:
(1) It must have a capacity equivalent to or greater than a skilled worker (both in work efficiency and painting quality).
(2) It should save energy.
(3) It should be able to paint walls with indentations and protrusions.
(4) Operation of the robot body and its moving equipment must be possible by one man control from a control room on the ground.
(5) The robot main body must use moving equipment that enables it to move precisely to its proper work position and maintain that position.
(6) It must have safe operation and must not have an adverse effect on the surrounding environment.

3. Description of the Painting Robot System

The automatic painting system using this painting robot consists of the robot main body which sprays paint, robot moving equipment to carry the robot main body to the proper work position, paint supply equipment and a controller to control the system. A view of the entire system is shown in Photo 1 and the painting system configuration is shown in Fig. 1.

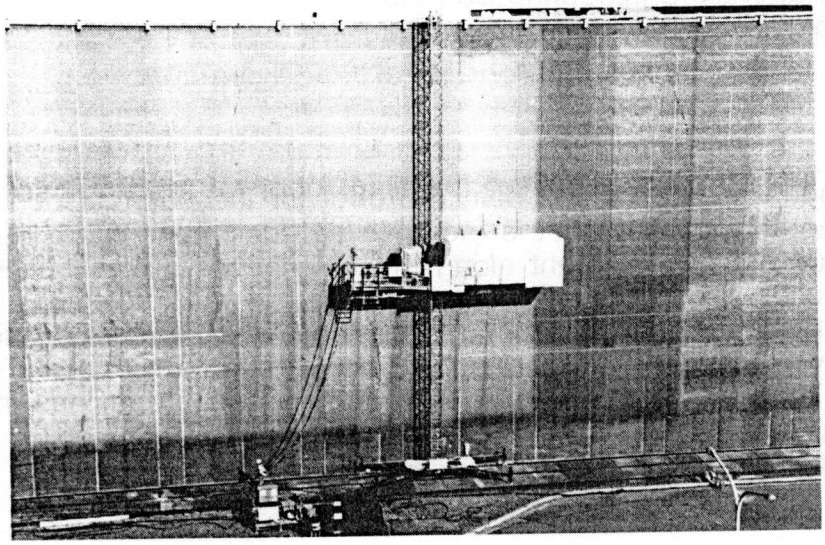

Photo 1 View of Automatic Painting System

3.1 Robot Main Body

The robot main body consists of a main frame, a painting gun, a gun driver and a control unit. The robot main body is shown in Fig. 2 and the painting gun is shown in Photo 2.

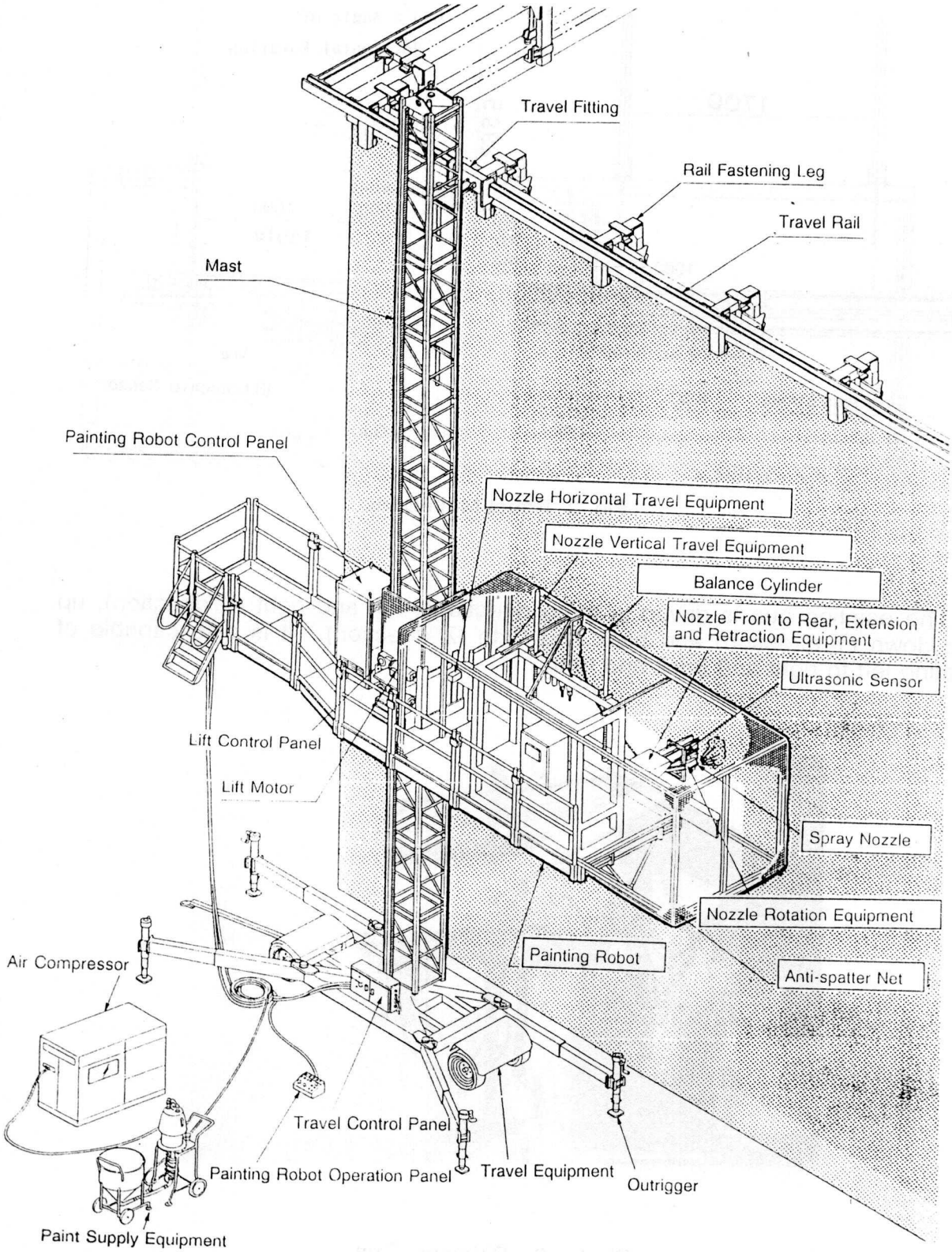

Fig. 1 Exterior Wall Painting Robot System Configuration

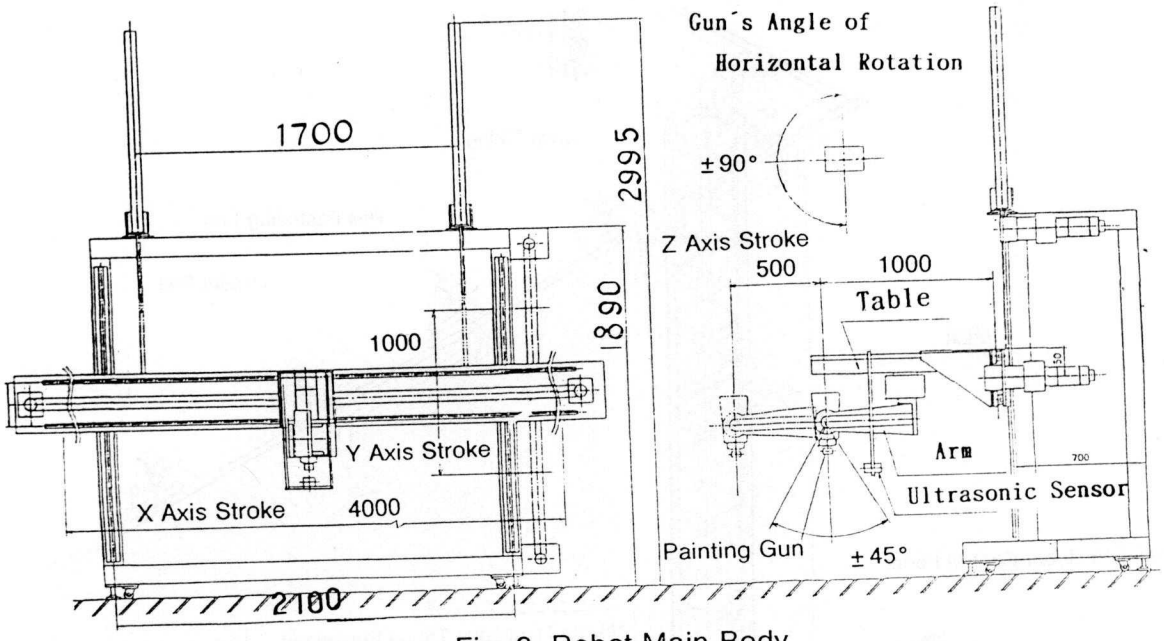

Fig. 2 Robot Main Body

The painting gun is driven in three directions, left and right (X direction), up and down (Y direction) and back and forth (Z direction). It is also capable of rotating left to right and back and forth.

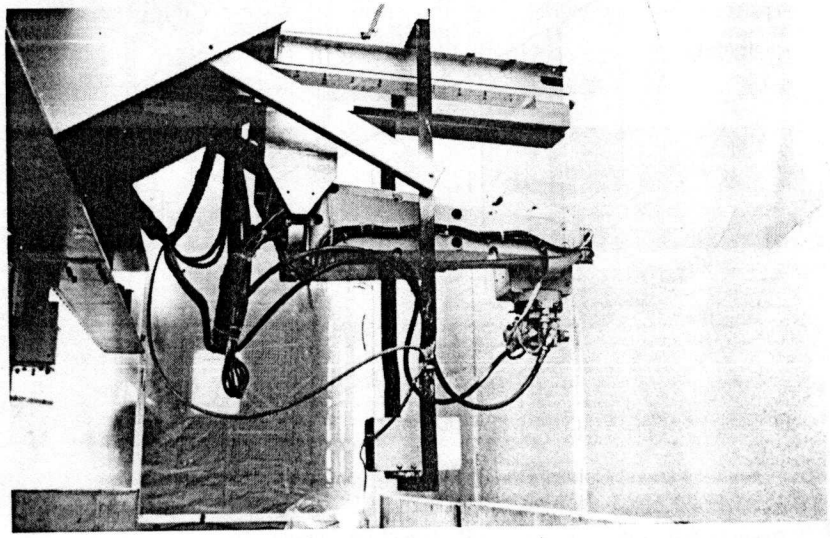

Photo 2 Painting Gun

Movement of the painting gun in the X direction is done by the X axis servomotor along a horizontal axis plate that acts as a positioning table. Movement of the painting gun along the Y axis is accomplished by Y axis servomotors which move the entire frame holding the horizontal axis plate along guide rails mounted in posts set on the left and right ends. A horizontal axis plate balancer cylinder is connected to the frame so that driving force will be applied uniformly when the horizontal axis plate is driven up and down.

Movement of the painting gun in the Z axis direction is accomplished by the Z axis servomotor driving the spray nozzle arm, which the gun is mounted to, along the positioning table. An ultrasonic sensor is mounted to measure the distance between the painting gun and the painted surface. Based on the measuring information from this sensor, the Z axis servomotor is controlled so that the distance from the painting gun to the painted surface is constant. In this way, the painting robot can paint walls which have indentations and projections and by moving around the indentations and projections, the gun nozzle can avoid colliding with the painted surface. Fig. 3 shows the nozzle path according to the painted surface. Rotating of the painting gun left to right and back and forth is done by a dual axis rotation servomotor in the rotating mechanism. Control of the speed of each servomotor is done by means of rotary encoders.

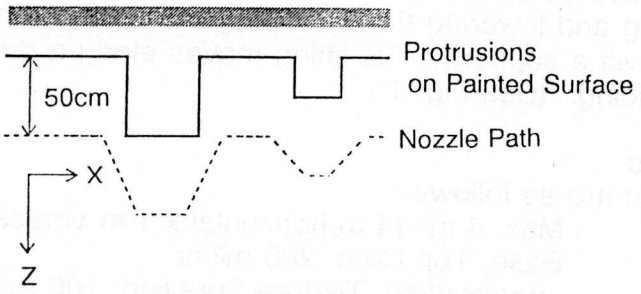

Fig. 3 Painted Surface and Path of Painting Gun

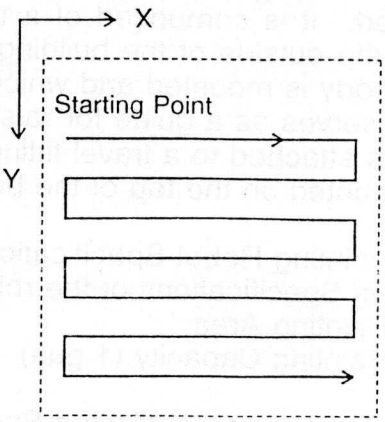

Fig. 4 Painting Pattern

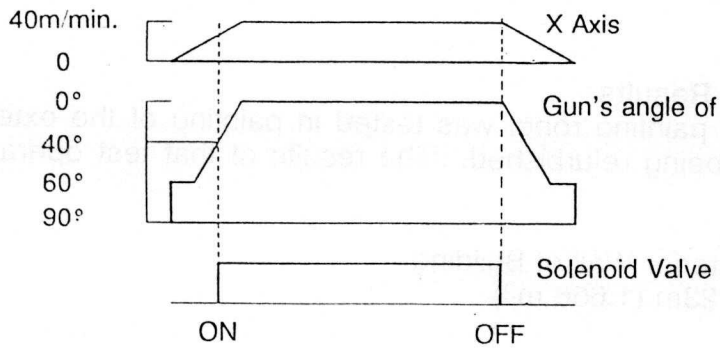

Fig. 5 Operation Timing

On-Off timing and speed of each servomotor as well as timing of the solenoid valves which turn the paint spray On and Off, etc., are controlled automatically by a personal computer unit, control panel and operation panel via control cables. Changes in the painting gun's speed and range of movement are accomplished automatically by the personal computer unit.

However, if a basic work pattern like that shown Fig. 4 is used in a painting job, the moving distance in the Y axis direction can have an effect on the painting pattern, causing nonuniformity. Also, the timing of the start of painting at the starting point and end point in the × axis direction as well as the angle of the painting gun with respect to the painted surface in the horizontal direction will have a great influence on the occurrence of run and sag of the paint. For these reasons, this robot is designed to control the nozzle's Y axis direction moving pitch and the On-Off timing of the solenoid valve at the paint spray starting and end points as well as the painting gun's angle of rotation, at the appropriate value for each type of paint so as to assure good painting quality.

Fig. 5 shows the relationship between the painting gun's angle of rotation in the horizontal direction and the On-Off operation timing of the solenoid valve with respect to the speed of the gun in the X axis direction.

3.2 Moving Equipment

For moving equipment, a movable work base which uses a mast was adopted. It is composed of a transporter which propels the moving equipment along the outside of the building being painted, a work stage on which the robot main body is mounted and which moves up and down automatically, and a mast which serves as a guide for raising and lowering the work stage. The top of the mast is attached to a travel fitting via a support. This fitting moves along a guide rail mounted on the top of the building. (See Fig. 1.)

3.3 Painting Robot Specifications

Main Specifications of the robot are as follows :

1. Painting Area	Max. 4 m^2 (4 m horizontal x 1 m vertical)
2. Painting Capacity (1 gun)	Base, Top Coat 200 m^2/hr Intermediate, Texture Spraying: 100 m^2/hr
3. Gun Horizontal Moving Speed	40 m/min.
4. Gun Vertical Moving Speed	8 m/min.
5. Gun Rotation Angle	Left/Right ±90°, Up/Down ±45°

4. On-Site Test Operation Results

The performance of this painting robot was tested in painting of the exterior wall of a building that was being refurbished. The results of that test operation are described below.

4-1 Painted Surface on Exterior Wall of Building

Length 72 m x Height 23m (1,656 m^2)

4-2 Painting Robot System

The configuration of the painting robot system was as shown in Fig. 1.

4-3 Painting Procedure

The flow of the automatic painting robot's painting procedure is shown in Fig.6.

4-4 Painting Results

It was confirmed that the robot demonstrated sufficient work efficiency and painting quality.

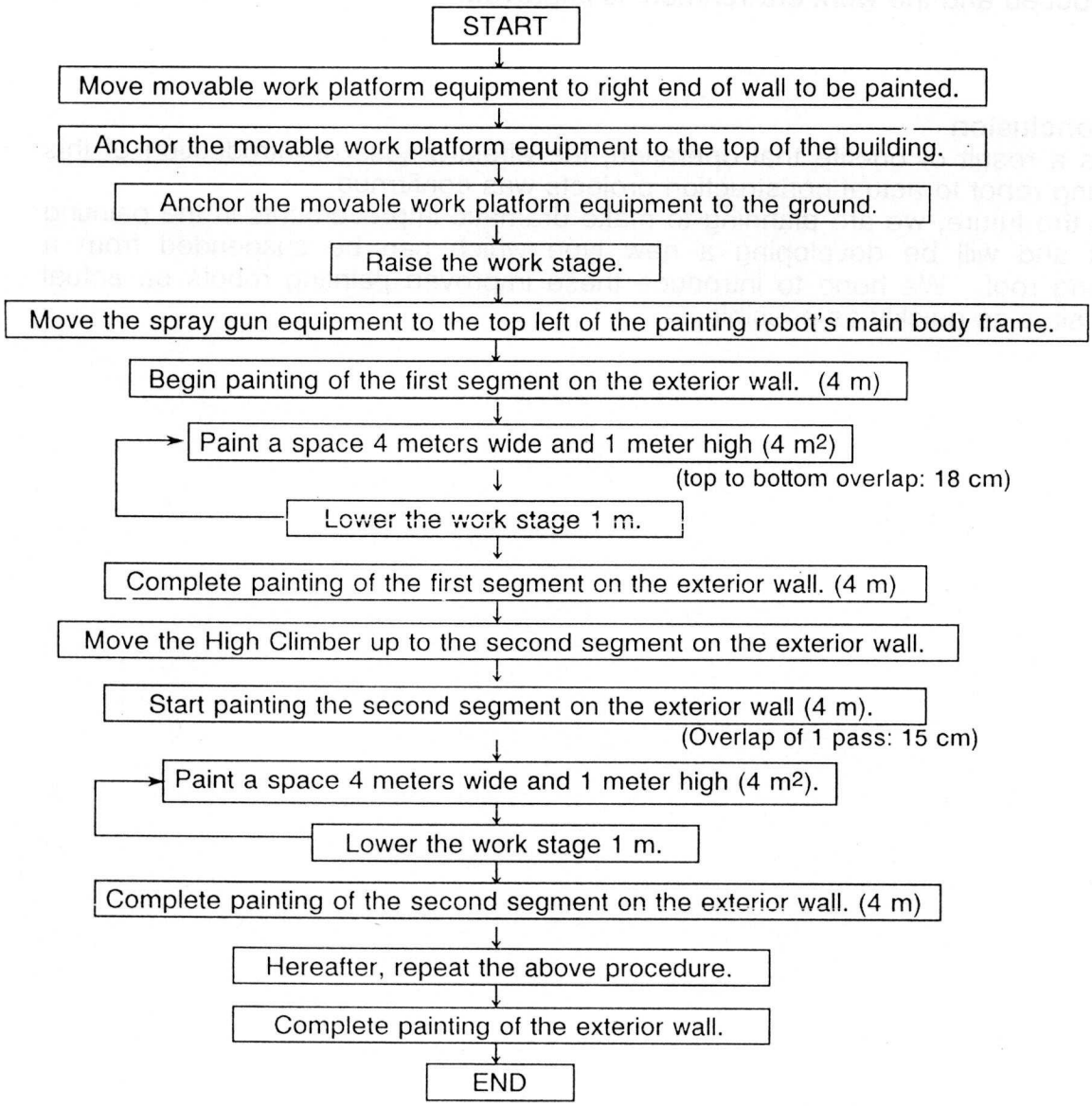

Fig. 6 Flow of Automatic Painting Robot Painting Procedure

5. Features of Painting Robot

The principle features of this painting robot are as follows.

1 It maintains painting quality which cannot be distinguished from the quality of skilled painting personnel.
2 Painting by manual labor on high scaffolding, as done previously, is eliminated, the work efficiency is high and there is little danger.
3 Uneven walls with indentations and protrusions can also be painted automatically.
4 Through automatic painting, the dirty work required with human workers is reduced and the work environment is improved.

6. Conclusion

As a result of on-site trial operation, the effectiveness of introduction of this painting robot to actual construction projects was confirmed.

In the future, we are planning to make dramatic improvements in the painting robot and will be developing a new type which can be suspended from a building roof. We hope to introduce these improved painting robots on actual work sites as quickly as possible.