# Research & Development on Robotic Systems for Assembly and Finishing work

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## Abstract

The aim of this paper is to explain four robotic systems for assembly and finishing work in building construction. "Mighty Shackle Ace" is a radio control auto-release clamp to execute steel column and beam erection safely and efficiently. "FLATKN" is a concrete slab finishing robot which provides high work efficiency and good finish quality. "CFR-1" is a ceiling panel positioning robot which successfully eliminates scaffolding and releases workers from heavy labor. "SSR-3" is a fireproof spray robot which is the third model in its series, and releases workers from a hazardous working environment.

## 1. Introduction

An international industrial robot exhibition was held in Tokyo in November 1987. During this exhibition a somewhat different category of robots, construction robots, was introduced by Shimizu and three other Japanese general contractors.

Research and development of construction robots was started about ten years ago. Studies and designs of robotic systems for various kinds of construction work were executed through projects funded by the Japan Industrial Robot Association (JIRA). Since these projects were initiated, actual construction robots have been developed by general contructors.

Recently, many kind of construction robots have actually been used, and some of them are on the market.

Japan's policy to increase domestic demand resulted in an increase in construction projects. As a result, the shortage of skilled construction workers became a serious problem, and expectations for construction robots are getting higher and higher.

This paper reports on four construction robots which were recently developed by SHIMIZU CORPORATION.

## 2. Radio control auto-release clamp (Mighty Shackle Ace)

### 2.1 Background

Structural steel erection is one of the most dangerous tasks to be robotized. In 1985 Shimizu developed the Mighty Jack, which is a remote assembly manipulator for steel beams. This enables us to reduce dangerous work. The Mighty Shackle Ace (MSA) is a radio control auto-release clamp for steel columns and beams. The MSA was developed as a brother of the Mighty Jack.

In steel frame construction work, columns and beams are carried by a crane. In this work, lifting tools such as clamps should be attached to a column or a beam before lifting, and the clamps should be detached after the column or beam is placed in position to be set. For this purpose, a skilled worker climbs to a high position to detach the hook while assuming an unbalanced posture. As a result, this job is regarded as highly dangerous.

### 2.2 Components and functions

Outside view of the MSA is shown in Photo 1. Components are shown in Figure 1. Specifications are shown in Table 1. The MSA consists of a control/power unit, lifting wire, operating wire and lifting tools (clamps). Electric motor drive cylinders, a high sensitivity receiver, a controller and batteries are assembled in the control/power unit. Strobo lights are also attached to its body in order to confirm the completion of operation.

As shown in Figure 2, the clamp is provided with a double locking mechanism for the sake of safety at the time of the detaching operation. The unlocking operation is carried out by an electric motor drive cylinder connected to a push pull wire in an operating wire sheath. An FM multiplex radio control system is provided to eliminate miss operations caused by interference.

During the operating procedure, the column is first grabbed by a lifting tool utilizing a bolt hole of the column, for example, locked by a worker and lifted up. It is carried by a crane, lowered and fixed into position, and then the lifting tools are automatically unlocked by means of wireless remote controller.

### 2.3 Results

Using this device, it is no longer necessary for a worker to climb up to high places to remove lifting tools. The operation, which used to require several minutes in the past, can be accomplished in a little more than 16 seconds. The lifting tools are easy to handle, so they can easily be attached by hand to the object to be lifted. It is not only applicable to columns and steel beams, but also to curtain walls, prefabricated units of steel reinforcement, etc.

The MSA has already been applied to more than 40 sites.

## 3. Concrete floor finishing robot (FLATKN)

### 3.1 Background

Concrete floor finishing work consists of a leveling step, a wood floating step and a trowel-finishing step. Among these steps, the final trowel-finishing step is the most difficult for the worker because the worker must push a trowel on the wet concrete floor in an awkward posture for a long period of time.

Furthermore, the number of skilled workers for concrete floor finishing work is decreasing these days. So, it has been difficult to gather enough skilled workers at construction sites.

### 3.2 Components and functions

Outside view of the FLATKN is shown in Photo.2. Components are shown in Figure 3. Specifications are shown in Table 2.

The FLATKN consists of travel rollers, a power trowel, a controller and a guard frame. A pair of travel rollers are attached at the bottom of the robot's main body. The robot can move back and forth, left and right, using DC motors in these rollers.

The power trowel mechanism has three supporting arms. Each arm has a rotating trowel assembly which has three trowels at the end of it. A gasoline engine is used as a power unit to drive the trowel assemblies, so that the trowel assemblies rotate on their axis, and simultaneously turn round the travelling device. Figure 4. shows one of the results of trowel movement computer simulation. The ratio of rotating speed to revolving speed is ten in this case. The result is good when this ratio is more than ten.

The angle between the concrete surface and the trowel can be adjusted by a cam mechanism. This angle is changed according to the hardness of the concrete surface to be finished.

The detachment of the robot with the guard frame is facilitated by a touch sensor safety device.

In addition to the gasoline engine for the trowel, the robot has a small generator which enables the robot to eliminate electric power cables, thereby increasing its mobility.

The FLATKN can be operated by radio remote manipulation. The hardness of the concrete surface to be finished is not uniform in the finishing area. The parameter of the robot should be changed according to the hardness of the surface, which is difficult to measure. Therefore, a remote-control system was adopted.

### 3.3 Results

The robot has been applied to actual construction sites since July 1987, and more than 60,000m$^2$ floor was finished by the robot totally. At the first site for robot application, 600 to 700 m$^2$ a day were finished utilizing this robot and two operators. Finishing quality and work efficiency were increased. The work efficiency is four to five times higher than comparable work using manual plastering. The labor force needed for night work can be decreased using the robot.

## 4. Ceiling panel positioning robot (CFR-1)

### 4.1 Background

Ceiling construction for office buildings, hotels and other commercial buildings is accomplished by a method using panels. Panels for the ceiling, called "plaster board", are made of plaster and covered with paper. The plaster board ceiling construction method accounts for about 70% to 80% of the ceiling construction market. A typical mid-size office building, for example, with 8 floors and 5,000m$^2$ requires 400 panels for each floor, totalling 3,200 pieces which must be set one by one.

The procedure for ceiling construction requires temporary scaffolding to be erected all over the floor and then cleared away for the next procedure. Human workers must assume an undesirable posture for the panel setting work. The workers must raise heavy(13.5kg) and large sized (910mm*1820mm) panels over their heads for placement against the hanging ceiling flat bars, and repitition of this work over a long period of time exhausts them. Sometimes ceiling construction results in a delay of the total building construction period because of the shortage of skilled panel setting workers.

### 4.2 Components and functions

Outside view of the CFR-1 is shown in Photo 3. Components are shown in Figure 5. Specifications are shown in Table 3.

The CFR-1 consists of a robot and a panel carrier which can be separated easily when transported. The robot is composed of a base frame with a travelling device and an X-Y table, a lifting arm with a panel holder, and a control box.

The angle of the panel holder can be changed with a swing mechanism. A compliant mechanism which enables easy positioning is attached between the lifting arm and the panel holder. The X-Y table is set at the bottom of the lifting arm in order to adjust panel position. The panel positioning sequence using the X-Y table and the compliant mechanism is shown in Figure 6. The robot travels at intervals of a panel length automatically through the use of the travelling device. This function is used to move to the next working position.

Ceiling construction work using the robot is accomplished as follows. The fully loaded panel carrier is attached to the robot (about 20 panels), and the robot is positioned under the location where the panel will be set. The robot uses the panel holder to remove one panel from the panel carrier and lifts it into position among the hanging ceiling flat bars. The robot correctly adjusts the position of the panel using the X-Y table automatically assisted by the compliant mechanism.

After that, a worker fixes the panel using an air screw driver. The robot travels to the next position to set the next panel.

4.3 Results

The CFR-1 raises a ceiling panel and positions it correctly. Operation of this robot is easy and good positioning accuracy is realized without skilled workers. In the conventional method, the workers erected temporary scaffolding all over the floor before handling the panels, and they are obliged to lift and support the panels themselves. The CFR-1 successfully eliminated the scaffolding and released the workers from the heavy task.

The advantages of the CFR-1 were confirmed through on-site application, and ceiling work efficiency increased 50% over conventional methods, due to the higher speed of setting work.

## 5. Fireproof spray robot (SSR-3)

### 5.1 Background

Fireproofing work is considered to be one of the most unpleasant tasks. The working environment is not good, as small particles of rock wool fill the surrounding environment.

Prototype robotic systems called SSR-1 (Shimizu Site Robot No.1) and SSR-2 were developed to investigate the possibility of roboticizing skilled construction work.

The SSR-3 is the third model in its series. The SSR-3 was developed as a useful and practical robotic fireproof spray system.

### 5.2 Components and functions

Outside view of the SSR-3 is shown in Photo 4. Components are shown in Figure 7. Specifications are shown in Table 4.

The SSR-3 consists of a vehicle, a manipulator, a distance sensor assembly and a control box. The manipulator has two degrees of freedom for arm motion and two degrees of freedom for wrist motion. A spray nozzle is attached to the top of the manipulator to move the nozzle, replacing a skilled worker.

The vehicle has two drive wheels at the center and four casters at each corner of the body. The vehicle moves back and forth, left and right, using a powered steering mechanism.

The SSR-3 has an ultrasonic sensor system to measure the distance from beams and adjust its position using this data. Two ultrasonic sensors are attached at the top of the telescopic pole, which can be adjusted according to the height of the beam to be sprayed. Using this sensor system, the robot can execute spraying work even when the robot is travelling along the beam.

Generally speaking, it takes much time to teach the sequence to the robot. An off-line teaching system was developed to reduce teaching time. This system is composed of a personal computer and digital cassette recorder.

Teaching data for the robot is created automatically by the system when the dimensions of a beam are input through the computer keyboard. When there are many holes on the beam, the place where a hole exists should not be sprayed. This system can be programmed to avoid spraying the holes.

### 5.3 Results

The prototype of the SSR-3 was developed in June 1986, and applied to two actual construction sites as a trial. However, the quality of robotic spray work was not comparable to that of a human worker. The item to be improved was the sensor system. The distance sensor of the prototype robot was set beside the spray nozzle. It couldn't operate while the robot was in operation, so the robot sprayed material using a wrist swing motion. As a result, the finished surface was not flat enough, especially at the connecting zone of each spraying pattern.

To overcome this problem, the sensor system was improved as described above.

The robot was applied to two sites after the sensor system was improved. The finished surface was flat and the appearance of the surface was almost as good as that of a skilled worker.

The uniformity of fireproofing thickness was improved by the new sensor system, and the SSR series was completed successfully.

## 6. Conclusion

Construction robots are now close to practical use. However, there are many problems to be overcome, such as technical problems and cost problems. On the other hand, effective construction robots are eagerly awaited to overcome the shortage of skilled workers.

Construction machines, which are called construction robots, are not always real robots. Presently, the simple construction machines are rather practical from the stand point of low-cost, easy operation and maintenance.

But the research and development of robotic technology for construction work is also important for future applications.

Therefore, construction research and development should be devided as follows:

1) Real robotic systems using high-technology for the future

2) Robots for current practical application

Universities and national laboratories are expected to execute the former R & D. Construction machinery manufacturers and general contractors will execute the latter R & D.

We hope that practical construction robots will be developed through the cooperation of all of these organizations.


## 7. Acknowledgement

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2) T.UENO, J.MAEDA, T.YOSHIDA, S.SUZUKI :"Construction robots for site automation", Proceedings of Conference on CAD and Robotics in Architecture and Construction, Marseille, 1986.

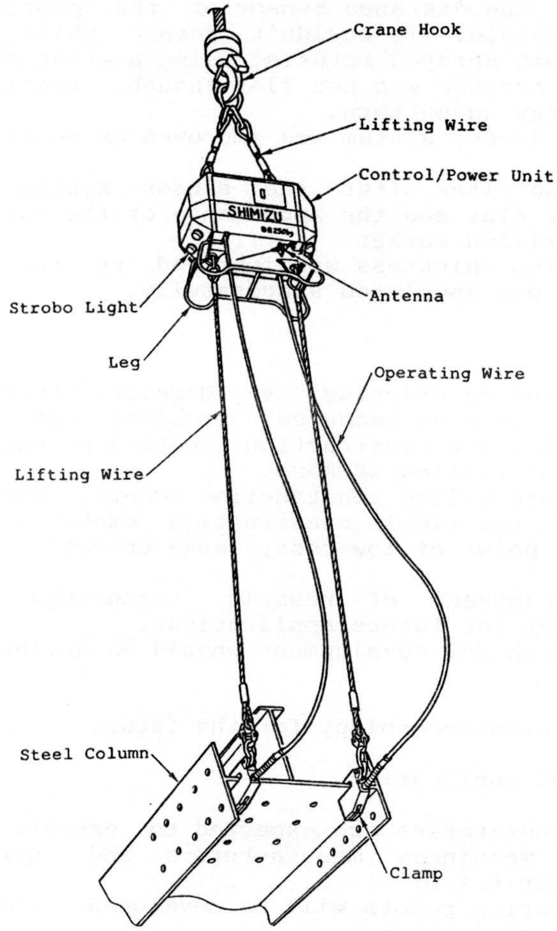



Figure 1. Components of the Mighty Shackle Ace

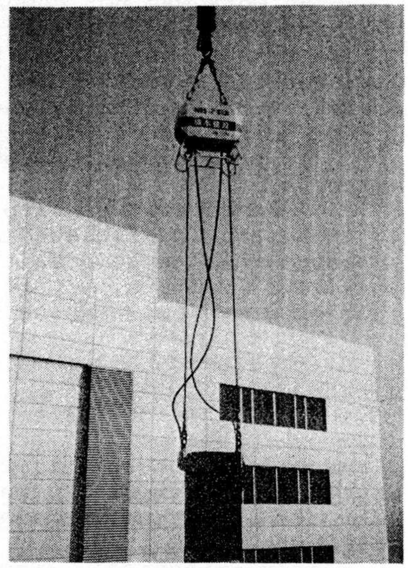


Photo 1. The Mighty Shackle Ace

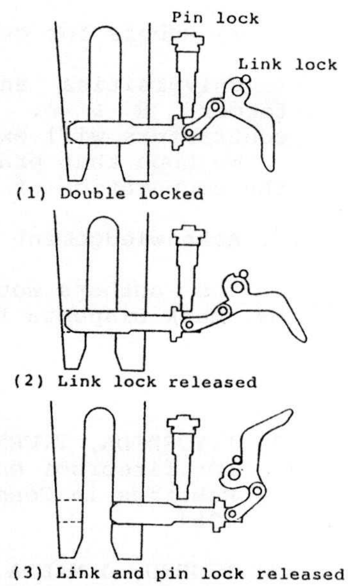



Figure 2. Double locking mechanism

Table 1. Specifications of the Mighty Shackle Ace

| | |
|---|---|
| Dimensions | width 415 mm<br>length 950 mm<br>height 965 mm |
| Weight | 250 kg (clamp 12kg) |
| Lifting capacity | 12 tons (15tons) |
| Power source | Battery (12V x 2) |
| Lock system | A double locking mechanism<br>1 link lock<br>2 pin lock |
| Control system | Wireless Remote Control<br>Effective distance = About 60m |

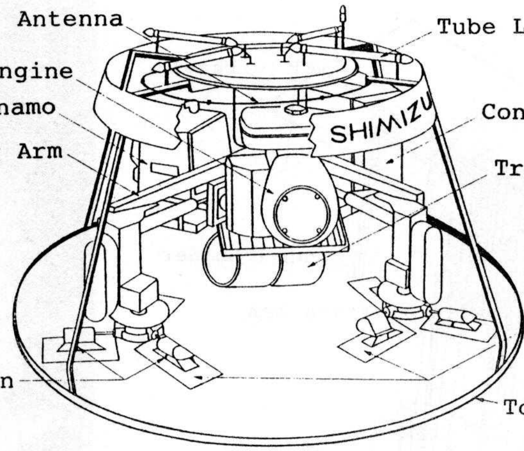



Figure 3. Components of the FLATKN

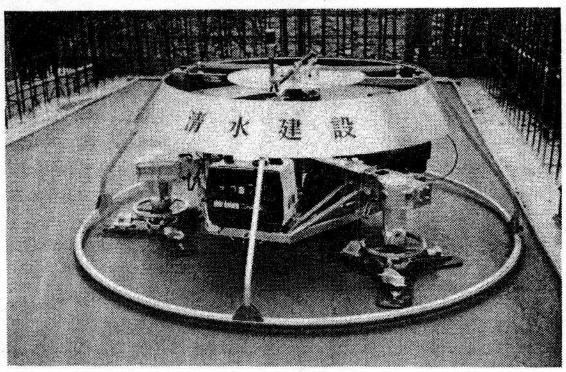


Photo 2. The FLATKN

Table 2. Specifications of the FLATKN

| | |
|---|---|
| Dimensions<br><br>Weight<br>Travel speed | maximum diameter 2300 mm<br>height 810 mm<br>300 kg<br>0 to 10 m/min |
| Trowel | Blade size L290, W150 mm<br>Rotating speed 70 to 100 rpm<br>Revolving speed 0 to 13 rpm<br>Blade angle 0 to 10 deg. |
| Power source | Trowel 5.5 PS engine<br>Travelling device 550 VA dynamo<br>and Controller |
| Control | By radio remoto control (FM,9ch)<br>- moving back and forth<br>- left or right turning<br>- left or right correction<br>- trowel rotating speed control<br>- travel speed control |
| Work Capacity | 400 to 800 $m^2/h$ |

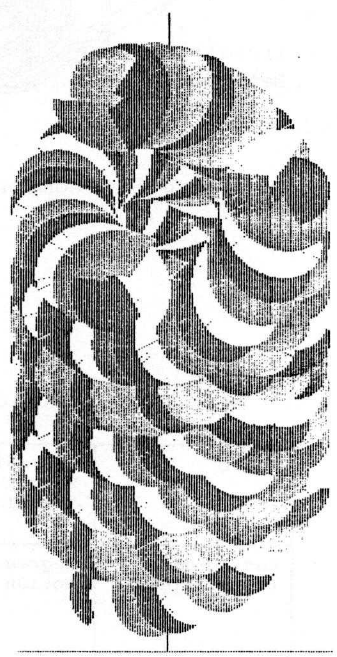


Figure 4.
Trowel moving pattern simulation result

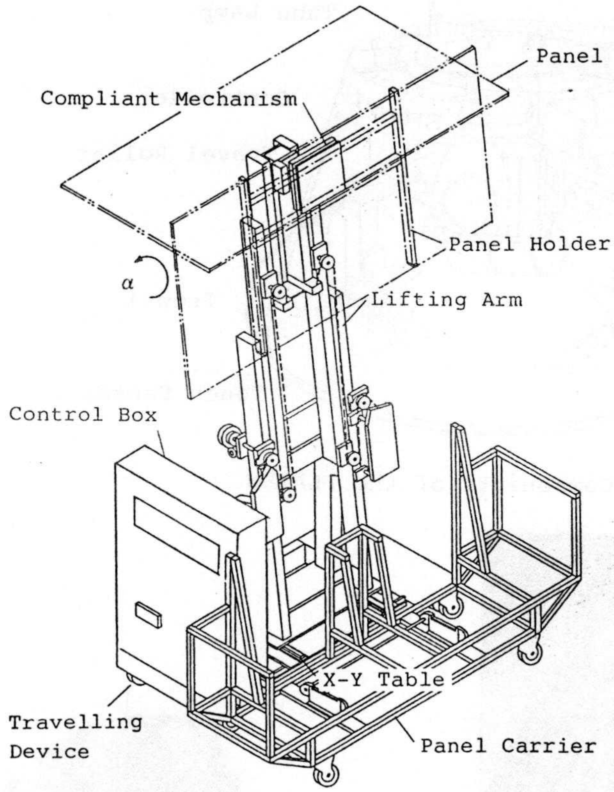



Figure 5. Components of the CFR-1

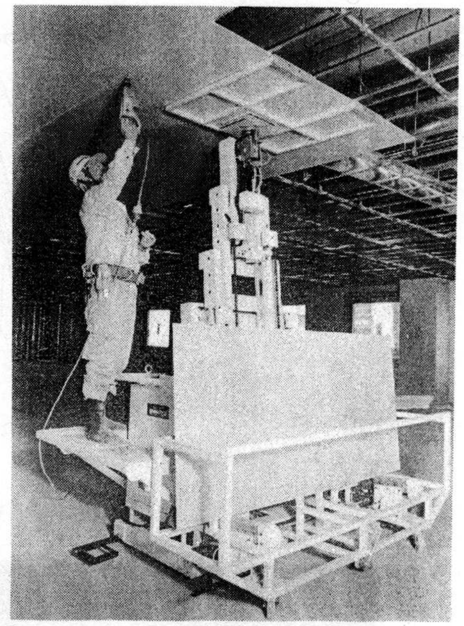


Photo 3. The CFR-1

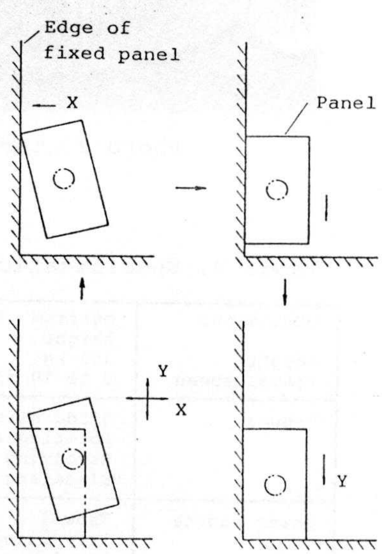



Figure 6.
Panel positioning
sequence

Table 3. Specifications of the CFR-1

| | | |
|---|---|---|
| Robot | Dimensions<br>Weight<br>Travel speed | L1380, W700, H1750 mm<br>300 kg<br>3 m/min (working)<br>30 m/min (trasporting) |
| Manipulator<br>(X-Y Table) | Degrees of freedom<br>Motion range | 4<br>X axis 300 mm<br>Y axis 150 mm<br>Z axis 1500 mm<br>α axis 90° |
| Panel carrier | Dimensions<br>Weight<br>Carrying capacity | L1900, W500, H1000 mm<br>50 kg<br>20 panels |
| Others | Power source<br>Panel size | AC100V, 50/60Hz<br>L1820, W910, T12 mm |
| Work Capacity | 25 panels/hour | |

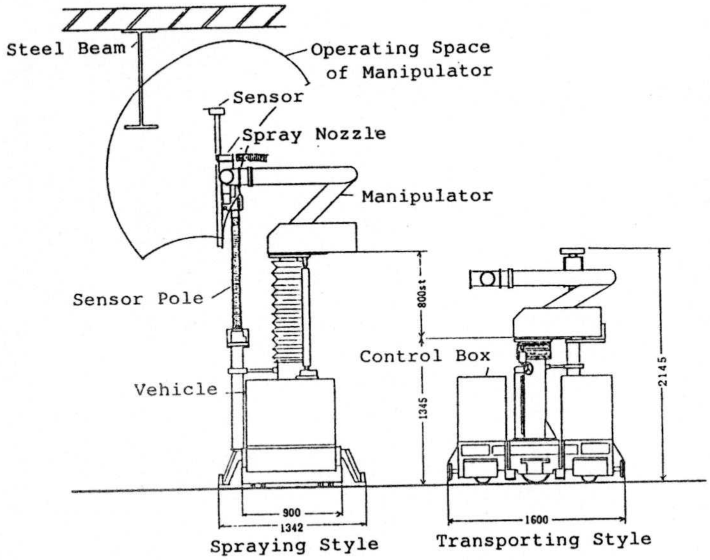



Figure 7. Components of the SSR-3

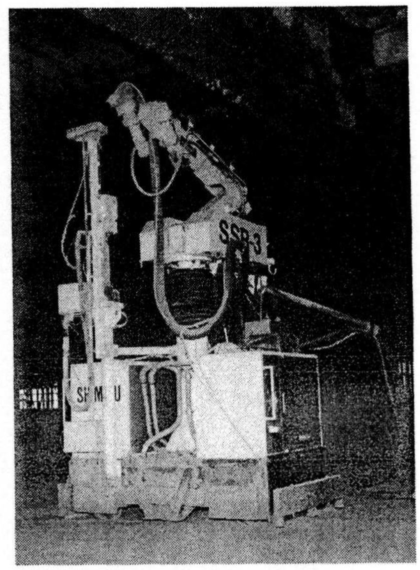
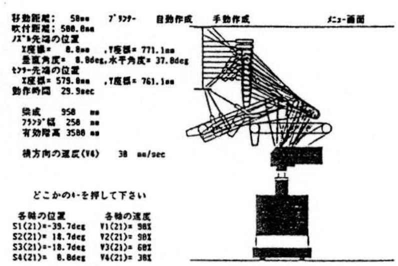


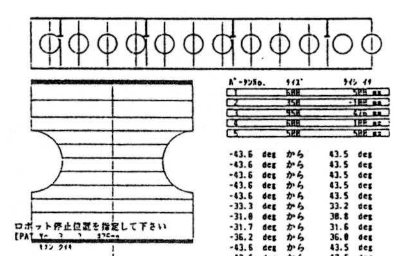

Photo 4. The SSR-3

Table 4. Specifications of the SSR-3

| | | | |
|---|---|---|---|
| Traveling device | | Degrees of freedom<br>Positioning<br>Traveling speed<br>Positioning precision | 2(traveling,revolution)<br>DC servo motor<br>max. 20m/min<br>±5mm |
| Manipulator | | Degrees of freedom | 4 |
| | Speed | Forward-backward turning<br>Up-down turning<br>Right-left swing<br>Up-down swing | max.18°/sec<br>max.18°/sec<br>max.60°/sec<br>max.60°/sec |
| | | Load capacity<br>Positioning<br>Positioning precision<br>Variable height | max.5kgf<br>DC servo motor<br>±3mm<br>max.800mm(manual) |
| Control functions | | Teaching functions | .PTP<br>.Manual data input<br>.Data input from cassette tape |
| | | Display<br>Memory capacity | 9"CRT and LED monitor<br>master program 100steps<br>block program 20steps<br>pattern program 30point 40patterns |
| | | Position correcting function<br>External signal | position correction by ultrasonic sensor<br>6 points |
| Others | | Safety function<br>Dimensions<br>Weight<br>Temperature<br>Power source | falldown prevention switch×4<br>bumper switch×2<br>emergency switch×3<br>length 1,600mm<br>width 1,050mm<br>height 2,145mm<br>1,000kg<br>0-40°c<br>AC100V,50/60Hz,20A |



(1) Arm motion data



(2) Wrist swing motion data

Figure 8. Off-line teaching system CRT screen image