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Teachingless Spray-Painting of Sculptured Surface by an Industrial Robot

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Abstract

The study deals with the automatic spray-painting by a 6-DOF industrial robot equipped with an air spray gun. Since the robot control commands generation for the spray-painting is manually performed by skilled workers using a teaching-playback function of a robot controller, the time, experience and patience are required. The study aims at making robot control commands without any special knowledge on spray-painting, in the case of bumpers of a car as an example of sculptured surfaces. The system can automatically generate a spraying path for the air spray gun on the basis of CAD date of the workpiece, and change the spraying path into robot control commands. From experimental results, the system is found to effective in painting bumpers of a car with an uniform paint thickness.

1 Introduction

The requirement to the automation of spray-painting is increasing since skilled workers of the spray-painting are decreasing while a variety of shapes and colors of products are increasing. The automation of spray-painting can be classified into two types; one is for large workpieces such as building and ship, and the other for small workpieces such as office furniture, small mechanical parts, car bodies, and so on.

With regard to the former, they are categorized as a construction machinery. The painting robots for the building or large wall consisting of the spraying unit hung from the edge of the roof with the wire are remote-controlled by the operator [1,2]. These robots may belong to a kind of manipulator. A multi-axis robot is also introduced for fireproof-coating to a steelwork [3]. Though an operator can teach the movement to the robot in off-line, the workpiece shape is limited to that defined in parametric expression.

With regard to the latter, the spray-painting machines with a spray gun moving up and down, called a reciprocator, have been used to automate spray-painting for small and simple products. However, the shape of products have become so complicated that the industrial robots have recently been introduced to cope with these requirements in various fields since they had high performance. Some of typical examples are a brazing robot detecting the 3-dimensional brazed point by the image processing unit [4], a deburring robot whose motion is controlled on the basis of human movement [5], and so on. In most cases, however, the robot control commands are generated with the teaching-playback function by the skilled workers at the field.

On the other hand, most of products at the present are designed with the CAD system. On the basis of CAD data consisting of geometric characteristics of the product, the robot control commands generated with correct dimensions and with no labor to enter dimensions of the workpiece all over again. Although some spray-painting robots are driven by data taught in off-line, using CAD data [6], they need the skill of workers to move them actually.

The study aims at the generating robot control commands of the spray-painting automatically without teaching. Thus, neither special knowledge nor skill is required any more. As a result, the automatic generation of the robot control commands for the spray-painting is realized on the basis of the CAD data of sculptured surface, i.e. bumpers of a car.

2 System Configuration

The system configuration is illustrated in Fig. 1. As soon as CAD data of the workpiece are given, a main processor generates a spray-painting path consisting of spraying points

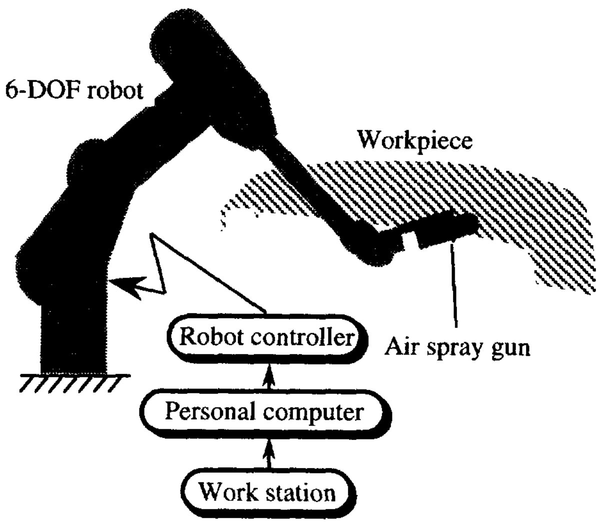

Fig. 1 Configuration of the spray-painting system

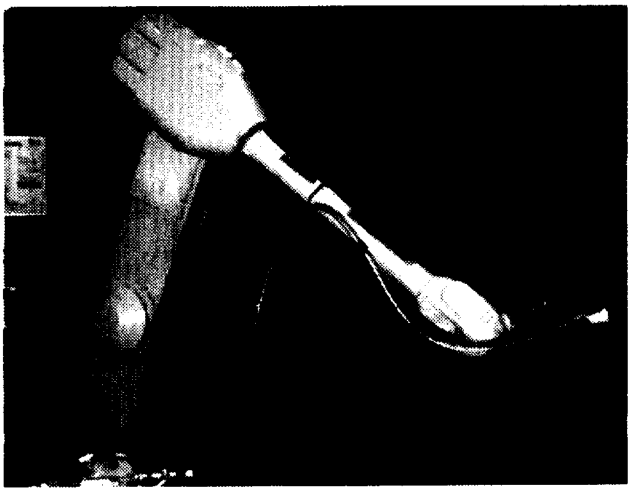

Fig. 2 Whole view of 6-DOF robot

and gun vectors on the EWS. A post processor converts the spray-painting path to the robot control command on the PC. The 6-DOF robot (Kawasaki-Asahi : EE10-A) shown in Fig. 2, is used, whose pay load is 10 N and whose arm is 3800 mm in length. As the spray-painting tool, the air spray gun (Asahi-Sunac : Micro Ace AGB20) is attached to the robot arm as shown in Fig. 3. The air gun has the arc-shaped painting pattern and needs to be set perpendicularly to the workpiece with 200 to 300 mm away from the workpiece surface.

3 Main-Processor

3.1 Definition of the spray-painting path

The locus of spray-painting gun is called "spray-painting path", which is generated as follows;

1) Some points are defined on the workpiece on the basis of the CAD data. The points are called "spray-painting points".
2) On the workpiece surface, the gun moves along the curves interpolating spraying points from the one edge to the opposite one of the workpiece. This curve and spraying points are called "spray-painting path element".
3) After passing a spray-painting path element, the gun moves to the start position of the next spray-painting path element. Therefore, the spray-painting path for a workpiece consists of a series of spray-painting path elements.

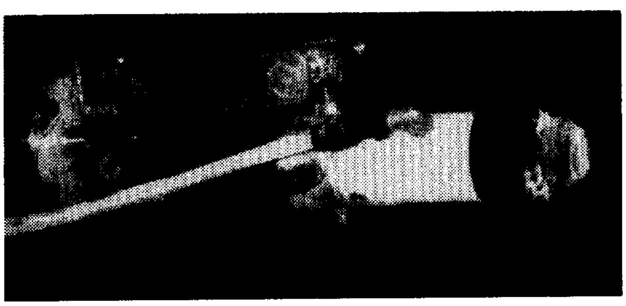

Fig. 3 Spray gun used in the study

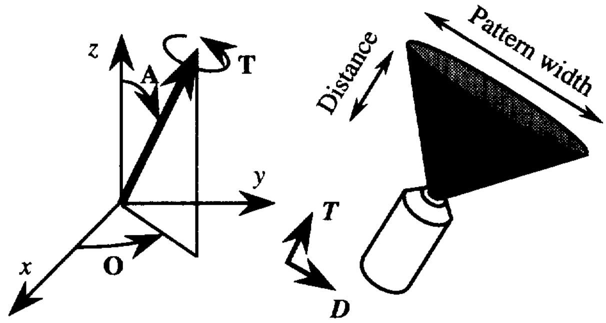

Fig. 4 Degrees of freedom necessary to set the spray tool to the designed attitude

When the spray-painting is performed, the attitude of the gun has to be kept perpendicular to the workpiece surface, and the direction of the gun around the axis is also kept constant due to the painting pattern of the gun. Therefore, the attitude of the gun is expressed by two vectors ***T*** and ***D***, where ***T*** is the gun vector for the direction of the gun, and ***D*** is the direction vector around ***T***, as shown in Fig. 4. The 6-DOF robot is required to attain such an attitude. The gun path includes these two vectors as well as the position information.

3.2 Generation of the initial spray-painting path

The outline of the spray-painting path generation is shown in Fig. 5. The system generates the spraying position, the gun vector and the direction vector as the initial spray-painting path.

CAD data of the workpiece must be prepared. Let us assume that the coordinate system of closed surface on the CAD system is (U,V) , which is mapped from the real

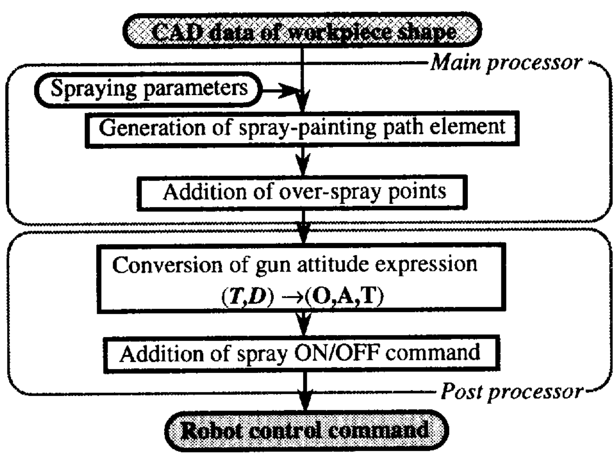

Fig. 5 Outline of spraying path generation

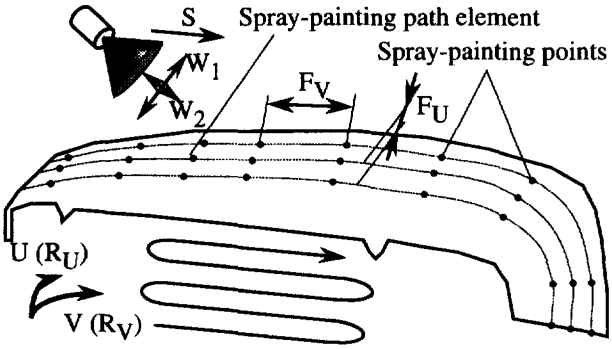

Fig. 6 Spray painting paths

dimension coordinate system (R_U,R_V). The parameters, W_1, W_2, L, and S with regard to spray-painting are prepared, where

W_1,W_2 : size of painting pattern
L : spray overlapping ratio
S : gun speed

These parameters are decided according to the production plan and the characteristics of the gun in advance as illustrated in Fig. 6. The interval of adjacent spray-painting path element and the division number of the spraying points on each spray-painting path element are determined according to the size of painting pattern. In case that the direction of spray-painting path element is parallel to the V-axis and the feed direction of spray-painting is perpendicular to the direction of painting pattern W_1, the interval of the adjacent spray-painting path element F_U is obtained as follows;

$$F_U = \frac{W_1 L}{100} \qquad \text{........................} \qquad (1)$$

According to the F_U, the division number in V-axis direction D_V is determined, when the calculated value on the UV surface is mapped to the $R_U R_V$ actual surface as follows;

$$D_V = \frac{R_V}{F_U} \qquad \text{........................} \qquad (2)$$

,where D_V is the integer value.

The interval F_V on spray-painting path element depends on the ratio of W_1, W_2 and Fu. It is determined as follows;

$$F_V = \frac{R_V}{D_V} \frac{W_2}{W_1} \qquad \text{........................} \qquad (3)$$

The division number in U-axis direction D_U is obtained in the same manner as D_V, as follows;

$$D_U = \frac{Ru}{Fv} \qquad \text{........................} \qquad (4)$$

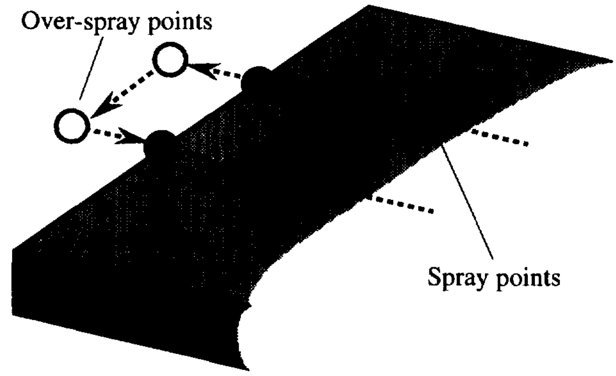

Fig. 7 Over-spray points

,where D_U is the integer value.

The position, the gun vector ***T*** and the direction vector ***D*** are generated on the CAD system according to D_U and D_V.

The spray-painting path consists of the position, the gun vector, the direction vector and the control code. The control code has a value corresponding to the condition, i.e. normal spraying point / the final point of the spray-painting path element, in order to control spraying and to generate over-spray points.

3.3 Generation of the over-spray point

When the spraying point is not on the workpiece, the supply of the paint is stopped to save the paint. However, the stopping or starting at the edge of the workpiece causes the time lag of spray-painting gun. Therefore, the spray-painting path element is extended in advance by using special points. These points, shown in Fig. 7 are called "over-spray point". The supply of the paint is stopped or started on the over-spray points to solve the problem occurring at the edge of workpiece.

Table 1 Example of robot control commands

```
.PROGRAM brdiv1()
 RESET
 HOME
  ACCURACY 300 ALWAYS
 SIGNAL 23
   SPEED  1000 MM/S
   JMOVE  TRANS( 929.81, -13.56,-196.73,179.45, 92.55,-178.46)
   LMOVE  TRANS( 869.87, -12.99,-199.40,179.45, 92.55,-178.46)
   SPEED  1000 MM/S
   JMOVE  TRANS( 867.66, -11.62,-149.47,179.45, 92.55,-178.46)
  SIGNAL -27
   SPEED  800 MM/S
   LMOVE  TRANS( 857.16, -7.37,  4.96,177.67, 96.27,-179.79)
  SIGNAL 27
   SPEED  800 MM/S
   LMOVE  TRANS( 829.67, -5.83, 117.49,174.57,118.84,179.45)
   SPEED  1000 MM/S
   JMOVE  TRANS( 805.62, -4.02, 161.29,174.57,118.84,179.45)
```

Table 2 Spraying condition

Room temperature :	19°C
Paint :	normal temperature dry type
Viscosity :	15 sec/NK-2
Spraying rate :	110 ml/min
Spraying pressure :	0.15 MPa
Mist air pressure :	0.2 MPa
Pattern air pressure :	0.15 MPa
Pattern width :	120 mm
Offset for spraying :	200 mm
Tool movement velocity :	800 mm/sec

4 Post-Processor

The spray-painting path generated by the main processor has to be translated into actual robot control commands with some extra information and conditions by the post-processor. The spray-painting path consists of a set of the position and vectors mentioned above. On the other hand, most of robot systems having 6-DOF adopt the unique angle expression in attitude respectively. The robot used in the system employs a specific attitude expression of three angle *O, A and T* as shown in Fig. 4. The attitude expressed by the vectors in spray-painting path is converted to the robot unique attitude expression.

Then, the extra spray-painting path have to be added to the spray-painting path, since the spray-painting path includes no path from the end of a spray-painting path element to the beginning of the next spray-painting path element. The retract / approach path has to be added to the original one, considering the speed, interpolation mode and the supply of the paint.

At the over-spray point, according to the control code, the system adds the command of starting or stopping of spraying to obtain the uniform paint thickness and paint saving. Considering above points, the position, angle and control code are determined for each spraying point. An example of robot control commands generated are listed in Table 1.

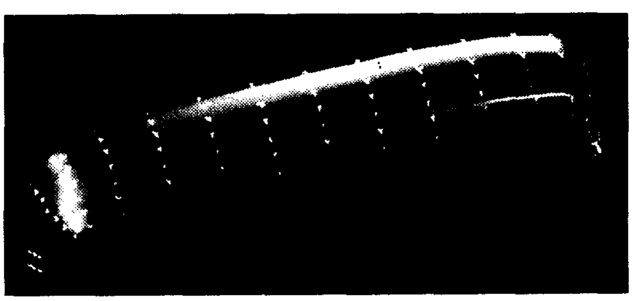

Fig. 8 CAD data of a bumper

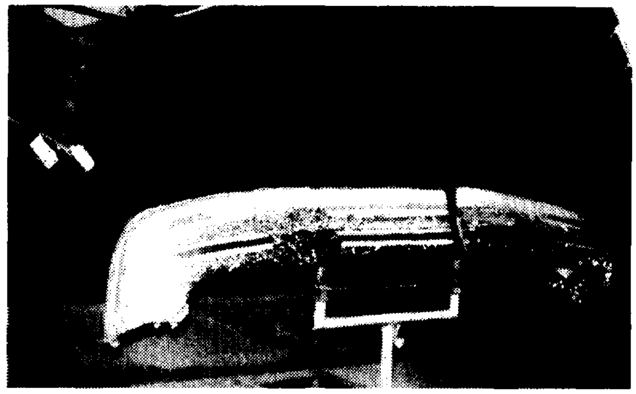

Fig. 9 Robot under spraying

5 Experiment

A spray-painting experiment was carried out for the sculptured surface under the condition listed in Table 2. The workpiece is a bumper of a car, whose size is 1750 mm × 300 mm × 350 mm. The spray-painting path automatically generated on the basis of CAD data is shown in Fig. 8. The spraying points are marked with x on CAD data. Using this spray-painting path, the experiment was carried out as shown in Fig. 9. Figure 10 is the measured distribution of the paint thickness. The typical paint thickness under the condition is supposed to be between 10 and 30 μm. The mean thickness of the paint is 19.6 μm at the corner part, 15.7 μm at the center part and 17.7 μm at the whole workpiece.

The paint thickness tends to be large at the corner part where the radius of curvature is small. Though the drastic change in the direction of the normal vector at the spraying point requires the quick change of gun attitude, the robot can not to catch up with the control commands of the movement. Thus, the gun can not attain the speed enough to obtain the desirable paint thickness. The paint thickness is also large at some points of workpiece edge since the shortage of the over-spray points makes the gun start spraying before the gun reaches the suitable speed for spraying. From the experimental result, it is found that the paint thickness exists within the allowance. The bumper after

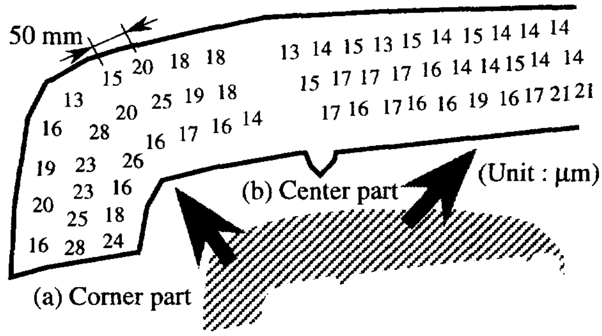

Fig. 10 Distribution of paint thickness

Fig. 11 Painted bumper

spray-painting is shown in Fig. 11.

Table 3 shows the comparison of the total spray-painting time for bumper by the conventional teaching method with that by the proposed one. It takes 500 min by the conventional teaching method, while 240 min by the proposed one.

6 Conclusion

The automatic spray-painting system for sculptured surfaces using an industrial robot on the basis of CAD system is developed. The results are summarized as follows;

1) The robot control commands are generated on the basis of CAD data without any special knowledge of spray-painting.
2) The spray-painting of bumper is performed with the paint thickness within the allowance.
3) The total spray-painting time by the developed system is decreased by 50% comparing it with the teaching by skilled workers.

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Table 3 Comparison of time required to spray painting

(Unit : min)	Teaching	Automatic
Setting of workpiece	10	10
Definition of path pitch and direction	30	30
Marking on workpiece	30	0
Check of robot movement	10	10
Teaching / Calculation	120	10
Singularity points check and correction by playback	180	60
Spraying condition check and correction	120	120
Total	500	240

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