'94 KACC (1994. 10. 17 ~ 20)

Coordination of Two Manipulators Using Force Torque Sensor
(Painting on the Three-Dimensional Surface)

Haruo NAKAJIMA*, Hirofumi ISHIDA*
Takakazu ISHIMATSU*, Fumio KASAGAMI**

*Dept. of Mechaical Systems Engineering, Nagasaki University
Bunkyo-machi 1-14, Nagasaki 852, Japan
**Mechatronics Division, Daihen Corp.Ltd.,
Minamisenrioka 5-1, Osaka 566,Japan

Abstruct
A Robot system to realize a painting using a writing brush is explained here. Based on the three-dimensional data about the target china , the movements of the writing brush is determined. The movement is realized by the movement of two robot manipulators which move coordinatedly.Experimental results reveals the applicability of one system.

1 Introduction

In the western part of Japan e.g. Nagasaki and Saga areas, the ceramic industry is popular, where traditional potteries and dishes are produced. In these areas it is desired to introduce automatic producing machines and new technologies in order to supply better products with lower price. Many manual tasks are now being replaced with machine tasks. While some painting tasks on the china was replaced with automatic machine tasks, traditional painting tasks using a writing brush are difficult to be replaced with machine ones. One reason of this difficulty is that in almost all cases the painting tasks are conducted on the three-dimensional curved surface. Already one technique called Pad Printing is practically developed to enable painting on the three-dimensionally curved surface. However, from the artistic point of view, the technique called Pad Printing is not satisfactory since this technique is not good at painting gray-scale patterns which are typical for the writing brush.

In order to enable a machine to paint using a writing brush, some problems need to be solved. The first problem is to obtain the three-dimensional information of the target china. Once the three-dimensional information is obtained, the movements of the writing brush is determined so that the resultant image on the china is observed without any distortion. The posture of the writing brush and the china need to be considered as well, since the printing using the writing brush is affected by the gravity remarkably.

Considering these difficulties, we developed one robot system which realizes painting on the three-dimensionally curved surface using a writing brush. One feature of this robot system is that coordinated movements of the two manipulators are introduced, where one manipulator moves the writing brush and the other manipulator moves the target china. In order to conduct traditional manual paintings, movements of the manipulators are coordinated considering the gravity effects. The three-dimensional shape of the target china is measured using a laser distance sensor which is mounted on the tip of one manipulator. Based on the three-dimensional data and desired pattern on the china, all coordinated movements of two manipulators are determined.

However, one problem still remains. The problem is how to compensate the mechanical error which is inevitable to the conventional manipulators. Therefore, a force torque sensor is mounted on one manipulator so as to detect the painting force and to compensate the mechanical errors of two manipulators.

Some experimental results reveal applicability of our robot system to painting tasks using a writing brush.

2 Configuration of Robot System

A robot system to realize painting tasks on the china using a writing brush is shown in Fig.1. These two manipulators are controlled by one robot controller, which is composed of a host computer and a set of parallel data processors(Transputer). Five parallel data processors are employed to enhance the computing ability.

On the tip of the tool manipulator, a force torque sensor is mounted. Due to this sensor, the force between the writing brush and the china can be controlled. Also a laser distance sensor can be mounted optionally there. The tool manipulator moves the sensor over the china and the sensor measure the global 3-dimensional shape of the china.

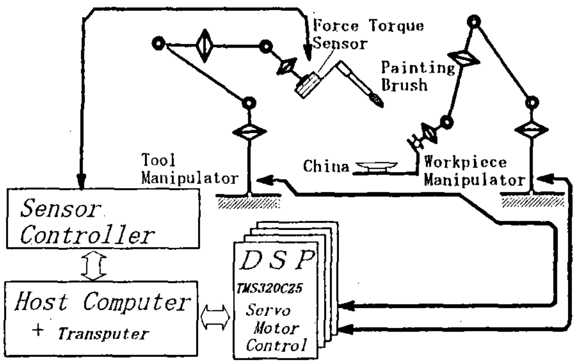

Fig.1 Hardware Implementation

3 Coordinate System and Coordinated Movement

For the coordinated movements geometrical relation between two manipulators is essential. Therefore, the coordinate system shown in Fig.2 is defined. Every symbol has the following meanings;

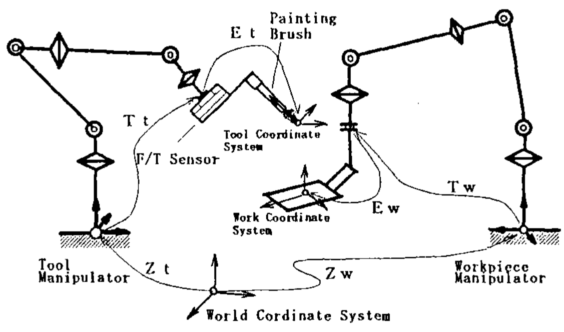

Fig.2 Definition of Coordinate System

Z_t:Homogeneous transformation matrix between world coordinate system and the tool manipulator.

Z_w:Homogeneous transformation matrix between world coordinate system and the workpiece manipulator.

T_t:Homogeneous transformation matrix of the tool manipulator.

T_w:Homogeneous transformation matrix of the workpiece manipulator.

E_t:Homogeneous transformation matrix of the tool.

E_w:Homogeneous transformation matrix of the workpiece.

Using the above transformation matrices, the position and the orientation of the china based on the world coordinate system is represented by the following equation.

$$(\text{worldXwork}) = Z_w \cdot T_w \cdot E_w$$

The position and the orientation of the brush based on the world coordinate system is represented by the following equation.

$$(\text{worldXtool}) = Z_t \cdot T_t \cdot E_t$$

The following relation is readily obtained from the geometrical relation.

$$(\text{worldXtool})=(\text{worldXwork})(\text{workXtool})$$

In the case of painting tasks the relative movements between the china and the brush are essential. Data (workXtool) represents how to move the writing brush on the china. Considering that the posture of the brush is usually settled normal to the target surface, data (workXtool) can be determined by the three-dimensional information of the china and the desired painting pattern. Data (worldXtool) represents the posture and the position of the writing brush in the world coordinate system. Considering the gravity effects on the painting result, the most desired direction of the brush is downward. Position of the brush in the world coordinate system is not important. Therefore, data (worldXtool) can be determined. Once data (worldXtool) and (workXtool) are determined, data (worldXwork) is determined by the following relation.

$$(\text{worldXwork}) = (\text{worldXtool}) \cdot (\text{workXtool})^{-1}$$

In our robot system, data(workXtool) is determined by the three-dimensional information of the china and the desired relative posture between the china and the brush. Data (worldXwork) is fixed at a convenient position and downward posture. During the painting task, only the china changes its position and its posture.

4 Projection of Desired Pattern onto the China Surface

Since the general surface of the china is three-dimensionally curved, painting task needs attentions so that the appreciated image is not distorted. However, the pattern appreciated differs depending on the position of the applicator and also the three-dimensional shape of the china. Therefore, the movements of the brush needs to be determined considering the position to appreciate the china and also the three-dimensional shape of the china. Skilled painter paints on the china considering the distortion of the image. Our robot system employed a function to measure the three-dimensional shape of the china. Furthermore, a perspective transformation technique is employed in order to give desired image to the applicator at prespecified location.

In the followings, one method to determine the movement of the brush is explained. Suppose one dish is appreciated at one viewing point as shown in Fig.3. And also suppose that the painting pattern on the dish needs to be appreciated as though the pattern is painted on the image plane without any distortion.

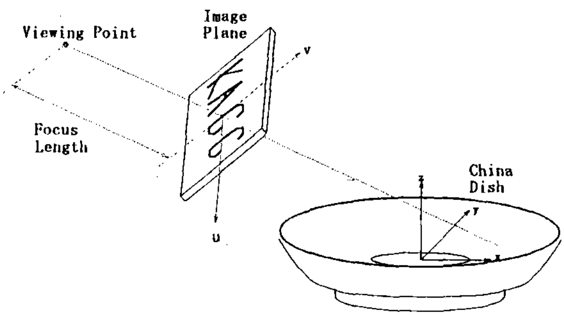

Fig.3 Desired Pattern and Projected Pattern

If we introduce coordinate system (u,v) on the image plane, relation between one point on the image plane and corresponding point on the china is represented by the following perspective transformation formula.

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \end{bmatrix} \begin{bmatrix} x \\ y \\ x \\ 1 \end{bmatrix},$$

where parameters h_{ij} denote geometrical relation between the image plane and are determined readily if the position and the posture of applicator are settled.

Eliminating λ in the above equation, we obtain the following simultaneous equations.

$$D \cdot p = b,$$

$$D = \begin{bmatrix} h_{31}u - h_{11} & h_{32}u - h_{12} & h_{33}u - h_{13} \\ h_{31}v - h_{21} & h_{32}v - h_{22} & h_{33}v - h_{23} \end{bmatrix},$$

$$p = \begin{bmatrix} x \\ y \\ z \end{bmatrix}, \quad b = \begin{bmatrix} h_{14} - u \\ h_{24} - v \end{bmatrix}.$$

Vector p to satisfy the above equation can be represented by

$$p = g + f\varepsilon,$$

$$g = D^T (DD^T)^{-1} b, \quad f = d_1 \times d_2$$

where $D^T(DD^T)^{-1}$ is a pseudo inverse of matrix D, vector d_i is i-th column vector of matrix D and ε is an indefinite scalar number. This equation means that the vector g corresponds to the position vector of the viewing point in Fig.3 and the vector f corresponds to the direction vector.

The above result is convenient to determine the desired movement of the brush. Firstly, we determine how to move the brush on the two-dimensional image plane.

Secondly, the movement on the image plane is projected onto the curved surface of the china. Since the three-dimensional surface data of the china are obtained in advance, projected points on the china are calculated as points where the vector p intersects the surface of the china.

5 Experiments

In order to test the applicability of our robot system, we had painting experiments.

The target china was a dish whose diameter was 150mm.

First of all, the three-dimensional shape of the dish was measured using the laser distance sensor. Distance data are measured at 140 points in the x direction and at 200 points in the y direction with 2mm interval.

Desired pattern employed was 'KACC 94'. Based on the technique mentioned in the chapter 4, projected trajectories of the brush on the china was determined. After that two robot manipulators start to paint on the china. While the brush is almost fixed., the china changes its position and posture as shown in Photo.1.

The painting on the china was satisfactory. From the prespecified viewing point the image is appreciated without any distortion of the pattern.

Photo.1 Robots Painting a Pattern

6 Conclusion

A robot system to realize painting task using a writing brush is developed.

This robot system is composed of two robot manipulators, one hold the writing brush and the other moves the china. Movements of the china are determined by the three-dimensional shape of the china.

Based on this determination, the robot system starts to work. However, because of the mechanical errors and environmental changes, movements of the manipulator need to be corrected so that the brush has enough force for the painting. One force torque toque sensor compensated the movements of the brush and the workpiece. The resultant painting was satisfactory.

References

[1]JanM.Tao,J.Y.S.LuhF.Zheng,"Compl-iant Coordination Control of Two Moving Industrial Robots", IEEE Trans.RoboticsAutomat.,Vol.6,No.3 , pp.332-330(1990)

[2] O.Alford and M.Belyeu ,"Coordinated control of two robot arms ",Proc.IEEE 1984 Int. Conf. Robotics (Atranta,GA) , pp.468-473(1984)

[3] K.Fernandez and E.Cook,"A generalized method for automatic down hand and xz control of a welding robot and positionar ",NASA Teach.paper2087 ,Feb.(1988)

[4] S.Ahmad and S.Luo ,"Coordinated Motion Control of Multiple Robotic Devices for welding and Redundancy Coordination though Constrained Optimization in Cartesian space ", Proc.1988 IEEE Inc.Conf.Robotics Automat, (Philadelphia),pp.963-968 (1988)

[5] F.Kasagami,T.Ishimatsu and M.Fujita, "Coordinated Motion of Playback Robot and Positioning Table ",Journal of Robotics Society in Japan,Vol.11-1,pp.165170(1992).

[6] Y.Shigehero,F.Kasagami,T.Ishimaytsu"3-D Vision Sensor for Arc Welding Industrial Robot System with Coordinated Motion",'92 Korean Automatic Control Conference,(Seoul,KOREA),Oct.19-21,1992,pp.382-387.

[7] H.Ishida,F.Kasagami,T.Ishinatsu,"3-D Vision Sensor System for Arc Welding Robot with Coordinated Motion by Transfer System ",93 Korean Automatic Control Conference , (Seoul,KOREA) , Oct.20-22,1993,pp.446-450.

[8] M.J.Margee , et, al .:Using Multisensory Imaje to Drive the Structures of Three Dimensional Object , A Review , CVGIP 32 , 147/157 , 1895.