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3-D Vision Sensor System for Arc Welding Robot with Coordinated Motion by Transputer System

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Abstract

In this paper we propose an arc welding robot system, where two robots works coordinately and employ the vision sensor. In this system one robot arm holds a welding target as a positioning device, and the other robot moves the welding torch. The vision sensor consists of two laser slit-ray projectors and one CCD TV camera, and is mounted on the top of one robot. The vision sensor detects the 3-dimensional shape of the groove on the target work which needs to be weld. And two robots are moved coordinately to trace the grooves with accuracy.

In order to realize fast image processing, totally five sets of high-speed parallel processing units (Transputer) are employed. The teaching tasks of the coordinated motions are simplified considerably due to this vision sensor .

Experimental results reveal the applicability of our system.

1 Introduction

It is wellknown that introduction of the coordinated motion to the robot system enables highly tactful and effective works. In the field of the arc welding, it is also wellknown that desirable welding performances can be achieved by the coordinated motion. Coordinated motions of arc welding systems are often realized by a pair of robots, one grasp the workpiece and the other moves the welding torch. Some welding robot systems to enable such arc weldings are already proposed, which are composed of two industrial robots and they move coordinatedly.

In order to realize such coordinated motions with conventional industrial robots, one important problem is that mechanical errors of robots need to be compensated since resultant errors of two robots effects as the sum of the mechanical error of both robots. As one practical solution of this problem is to use two teach and playback robots, since the mechanical errors of robots are compensated by the operator during the manual teaching task.

As everyone notices, teaching tasks of coordinated motion need some skill and a lot of working time, because operators should consider the relative posture and location between the welding torch and target workpiece. Therefore, previously we have proposed one robot system to simplify teaching tasks of coordinated motion. Due to this system, teaching tasks can be simplified, however, some skill and relatively long working time is still needed.

In order to solve this problem, the 3-dimensional vision sensor system with the high-speed parallel processors (Transputers) to simplify the teaching task is developed. Futhermore, a technique to generate new teaching points corrected autonomically is also developed.

In this paper we present an arc welding robot system to realize coordinated motions with 3-dimensional vision sensor using Transputer System. The vision sensor is mounted on the top of the robot arm holding the welding torch. The image data obtained from the vision sensor is processed by the parallel data processing unit(Transputer), and the 3-dimensional information, posture and direction, of the target groove is obtained. Using this vision sensor, one method to simplify the teaching task is proposed. Following the proposed method, the operator has to specify (teach) only starting and ending points of welding even if the welding grooves are not straight.

The above teaching is performed by moving only one robot to grasp the welding torch. After the teaching, two robots move along the welding grooves based on the teaching data and the sensor information.

Based on the data obtained during this operation, the teaching data is corrected to realize desirable coordinated motions of the robots. Resultant teaching data are used for the following welding tasks.

Experimental results reveal the applicability of our sysytem.

2 Coordinated Motion for the Welding Torch

Suppose the continuous welding along the outer periphery of an ellipse. Desired welding process can be realized by the coordinated motions of a pair of manipulators. Since the slope of the welding surface greatly influences the depth of the welding puddle, a desirable welding needs to move the welding target considering the gravity. Therefore, one desirable control of the robot motion is reqired to satisfy the following conditions as shown in Fig. 1.

(1) Maintain the slope of the welding surface.
(2) Maintain the posture of the arc-welding torch relative to the welding surface.
(3) Maintain the travelling speed of the arc welding torch relative to the workpiece.

In order to teach such coordinated motions, the conventional method is to move the both robots considering the interference between the workpiece and the welding torch.

It is readily noticed that the 3-dimensional vision sensor might simplify these cubersome teaching tasks. However, it is important to develop some control algorithm to determine how to use 3-dimensional data in order to move two robots coordinately satisfying the desirable welding conditions mentioned above. In the following we propose one algorithm to depict how to use 3-dimensional vision sensor for the teaching task of coordinated motions.

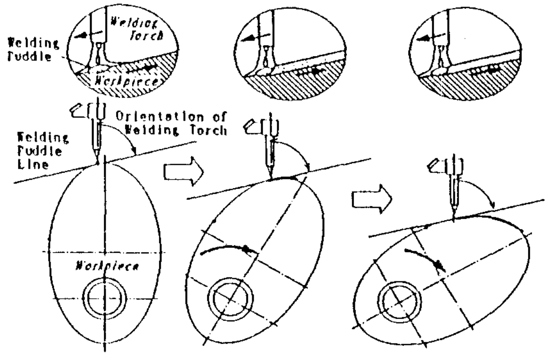

Fig. 1 Desired Motion of Arc Welding

3 Configuration of the Robots System

Configuration of our robot system is shown in Fig. 2. One manipulator hold the welding torch and the other grasp the workpiece through the gripper. On the welding torch, in order to detect the posture and direction of the target groove , the 3DSS (Three-Dimensional Seam Sensor) is mounted. In order to enhance the computating speed of controllers of two robots and processing of the image data from the 3-dimensional vision sensor, pararell data processors(Transputer) are employed here. Control data calculated with pararell data processor are sent to the servo control block equipped with DSP(Digital Signal Processor) through the host computer. The servo control block specifies movements of servo-motors mounted on each joint of two robots.

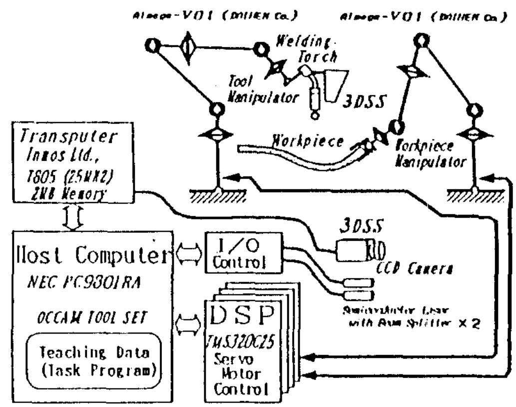

Fig. 2 Hardware Implementation

For the coordinated motions enabling desirable weldings, relative posture between the welding torch and the workpiece is important. Therefore, we define coordinate systems as shown in Fig. 3. The meaning of symbols in Fig. 3 are as follows.

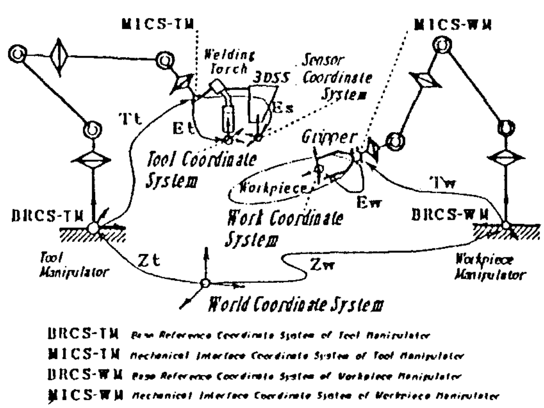

Fig. 3 Definitions of Coordinate Systems

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

- Z_w: Homogeneous transformation matrix of the between world coordinate system and workpiece manipulator.
- T_t: Homogeneous transformation matrix of the torch manipulator.
- T_w: Homogeneous transformation matrix of the workpiece manipulator.
- E_t: Homogeneous transformation matrix of the tool.
- E_s: Homogeneous transformation matrix of the sensor.
- E_w: Homogeneous transformation matrix of the gripper.

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

$$(\text{world X work}) = Z_w \cdot T_w \cdot E_w \qquad (1)$$

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

$$(\text{world X tool}) = Z_t \cdot T_t \cdot E_t \qquad (2)$$

Therefore, the following relation is obtained.

$$(\text{world X tool}) = (\text{world X work}) \cdot (\text{work X tool}) \qquad (3)$$

In the coordinated motion of our welding robot, the relative position and orientation between the torch and the workpiece (workXtool) is specified since the relative movements between two robots are essential in the case of welding task. It is interesting to note that if one of (world X tool) and (world X work) are specified ,then the matrix determined automatically by Eq.(3).

4 3-Dimensional Vision Sensor(3DSS)

3DSS (Tree-Dimensional Seam Sensor) is mounted on the tip of the torch manipulator so as to detect the target groove in front of the welding torch as shown in Fig. 4. Two semiconductor laser beams are expanded into the one direction with a rod lense to lighten the target groove. Image data are fetched by a CCD camera and are sent to the parallel data processing units (Transputers) to deal with the image processing.

The origin of the sensor coordinate system is settled at the center of the first laser slit-ray. Using the slit-ray projection method, one Transputer computes the posture α, β, γ and location Y, Z of the target groove from the fetched image data . One example of the image data of a target groove is shown in Fig. 5. Using this example, we show procedures to give these data in the followings.

First, the coordinates of point C_1 and C_2 based on the sensor coordinates are obtained by the image processing, where C_1 is the top of the groove lighten with the first laser slit-ray and C_2 is the corresponding point on the second laser slit-ray.

Secondly, the two vectors V_1 and V_2 which represent the direction of the projected light on the groove.

Thirdly, the inclination angles α, β, γ to represent the posture (orientation) of the target groove are obtained by the following equations as shown in Fig. 6.

$$\gamma = \tan^{-1}\left(\frac{Y_{c2} - Y_{c1}}{H}\right) \qquad (4)$$

$$\beta = \tan^{-1}\left(-\sin\gamma \cdot \left(\frac{Z_{c2} - Z_{c1}}{Y_{c2} - Y_{c1}}\right)\right) \qquad (5)$$

$$\alpha = \tan^{-1}\left(\frac{-\cos\gamma \cdot (v_{1y} + v_{2y})}{\sin\gamma \cdot \sin\beta \cdot (v_{1y} + v_{2y}) + \cos\beta(v_{1z} + v_{2z})}\right) \qquad (6)$$

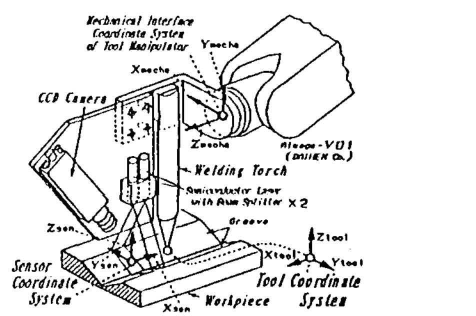

Fig. 4 Vision Sensor 3DSS

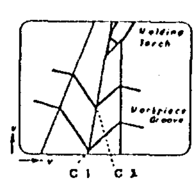

Fig.5 Image Data from 3DSS

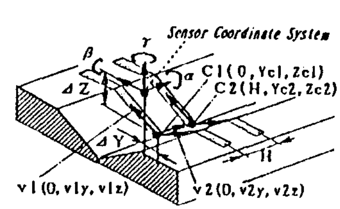

Fig.6 Detection of the Posture and Location

5 Correction of Teaching Data

3DSS sensor is used to detect the welding groove in order to correct the movement of the robots, so that the welding torch is moved along the welding groove satisfying a desirable welding posture and position.

We assume that desirable location and posture of the target groove are represented by Y_0, Z_0, α_0, β_0 γ_0 and γ_0. It should be noticed that these coordinates are based on the sensor coordinate.

Suppose that robots are moving and the data Y_i, Z_i, α_i, β_i, γ_i from the 3DSS are obtained. Since the data obtained are differ from the desirables ones, the movement of the data should be corrected. One algorithm is proposed in this Section. In the following, $(\ X\ )_{cor}$ denotes the matrix corrected by the sensor to give the desirable location and posture. $(\ X\ )_0$ denotes the matrix calculated without sensor information.

(1) Correcting matrix based on the sensor coordinate system is defined by

$$U = Trans(0,(Y_i - Y_0), (Z_i - Z_0)) \cdot Rot(Z, (\gamma_i - \gamma_0)) \cdot Rot(Y, (\beta_i - \beta_0)) \cdot Rot(X, (\alpha_i - \alpha_0)) \qquad (7)$$

(2) Using the above matrix, we can calculate the location and posture of the robot with the welding torch to give the desirable sensor data Y_0, Z_0, α_0, β_0, γ_0 by the following equation.

$$(work\ X\ tool)_{cor} = (work\ X\ tool)_0 E_t^{-1} \cdot E_s \cdot \Delta U \cdot E_s^{-1} \cdot E_t \qquad (8)$$

(3) It should be noticed that Eq.(8) specifies the relative location and posture between two robots. Therefore, in order to realize desirable welding conditions mentioned in Section 2, the posture of the robot with the welding torch shouldn't be changed, because changing the posture of the welding torch deteriorates welding performance.

Therefore, the robots with the welding torch should move keeping its posture constant and also satisfying Eq.(8). Considering these situations, we determine the movement of two robots.

$$(world\ X\ tool)_{cor} = (world\ X\ tool)_{dum} \cdot E_t^{-1} \cdot E_s \cdot \Delta W \cdot E_s^{-1} \cdot E_t \qquad (9)$$

$$(world\ X\ work)_{cor} = (world\ X\ tool)_{cor} \cdot (work\ X\ tool)_{cor} \qquad (10)$$

where

$$\Delta W = Trans(0,0,0) \cdot Rot(X, (\alpha_0 - \alpha_i)) \cdot Rot(Y, (\beta_0 - \beta_i)) \cdot Rot(Z, (\gamma_0 - \gamma_i)) \qquad (11)$$

$$(world\ X\ tool)_{dum} = (world\ X\ work)_0 \cdot (work\ X\ tool)_{cor} \qquad (10)$$

The above control algorithm means that the robot with welding torch moves changing its location and keeping its posture. Whereas, the robot with the workpiece moves changing its posture and keeping its location. When we apply the above algorithm, there still remains a problem that since some delay is inevitable to obtain the data from the 3DSS some considerations are needed, typically when the robots moves with high-speed.

6 Teaching Task of the Coordinated Motion using 3DSS

We apply the 3DSS in order to simplify the teaching tasks of the coordinated motions. Considering the time delay of 3DSS, the following teaching procedures are employed as shown in Fig. 7.

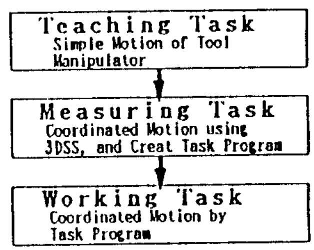

Fig. 7 Procedure for Coordinated motion of Arc Welding

(1) Teaching Task: The operator moves only one robot which grasps the welding torch and teaches the posture and the location at starting point and the end point of arc welding. This teaching operation needs not to be accurate since the data are corrected by the 3DSS. Teaching data obtained here are used to specify (work X tool)

(2) Measuring Task: Next, two robots are moved in order to generate more detailed and accurate teaching data. Here, two robots moves automatically without any manual operation. Two robots reproduce the motion based on the teaching data. However, motions of the torch and the workpiece are controlled coordinately so that relative movements between two robots satisfies (work X tool) specified. Of course, 3DSS corrects the (work X tool) so that the desirable relative posture and location is satisfied. The robot with the welding torch moves keeping its posture specified at the initial point. Whereas, the robot with the workpiece moves keeping its welding position.

During this operation, while 3DSS corrects the

movements of robots, sometimes resultant movements are not satisfactory because of the time delay of 3DSS. In order to cope with this program,
data related with the movements of two robots and also data from 3DSS are stored . These data are used in the following working task.
(3) Working Task: Two robots execute welding tasks. Task program of this movements are created from the data obtained in the previous measuring task.

7 Experimental Result

We had a experiment, where the welding work was twisted as you can seen in Photo. 1. Two points on the work was specified by the operator moving the left-hand side robot. First data specifics the welding condition at the starting points. And the second data specifics that at the ending points. After the measuring and working task, we confirmed that two robots moves coordinately , the left-hand side robot was keeping its posture and the right-hand side was keeping its location.

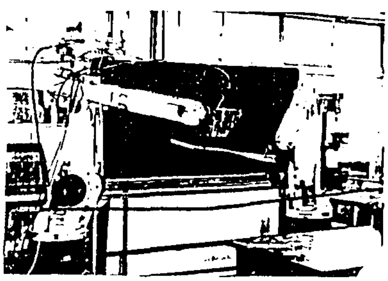

Photo. 1 Coordinated Motion of Two Arm Robots

8 Conclusion

In this paper we presented a 3-dimensional vision sensor for an arc welding robot system with coordinated motions. Furthermore, we proposed one control algorithm of coordinated motions using this 3-dimensional vision sensor. Considering the redundancy of the robots, movements of both robots are determined so as to realize a desirable arc welding., where the welding arc is moved keeping its posture and workpiece is moved keeping its location. Due to the 3-dimesional vision sensor, teaching tasks of the coordinated motions are simplified remarkably. Teaching tasks needed here was to specify only a few points by moving only one robot.

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