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3-D Vision Sensor For Arc Welding Industrial Robot System with Coordinated Motion

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1 Introduction

In order to obtain desired arc welding performance, we already developed an arc welding robot system that enabled coordinated motions of dual arm robots. In this system one robot arm holds a welding target as a positioning device, and the other robot moves the welding torch.Concerning to such a dual arm robot system, the positioning accuracy of robots is one important problem, since nowadays conventional industrial robots unfortunately don't have enough absolute accuracy in position. In order to cope with this problem,our robot system employed teaching playback method, where absolute error are compensated by the operator's visual feedback. Due to this system, an ideal arc welding considering the posture of the welding target and the directions of the gravity has become possible. Another problem still remains, while we developed an original teaching method of the dual arm robots with coordinated motions. The problem is that manual teaching tasks are still tedious since they need fine movements with intensive attentions. Therefore, we developed a 3-dimensional vision guided robot control method for our welding robot system with coordinated motions.

In this paper we show our 3-dimensional vision sensor to guide our arc welding robot system with coordinated motions. A sensing device is compactly designed and is mounted on the tip of the arc welding robot.The sensor detects the 3-dimensional shape of groove on the target work which needs to be weld. And the welding robot is controlled to trace the grooves with accuracy. The principle of the 3-dimensional measurement is depend on the slit-ray projection method. In order to realize a slit-ray projection method, two laser slit-ray projectors and one CCD TV camera are compactly mounted.

Tactful image processing enabled 3-dimensional data processing without suffering from disturbance lights. The 3-dimensional information of the target groove is combined with the rough teaching data they are given by the operator in advance. Therefore, the teaching tasks are simplified tremendously due to this vision sensors. In some cases where the shape of the target work is simple enough, the teaching tasks can be omitted due to this vision sensor.

2 Definition of Coordinate Systems

Two robots, here we consider,are 6 axis manipulators as shown in Fig. 1. Suppose one robot acts as a positioner and the other act as a welding tool. In order to realize the coordinated motion, the relative position and orientation between the torch and the workpiece need to be considered. Therefore, we introduce coordinate systems shown in Fig. 2.

Notations in Fig. 2 are as follows:

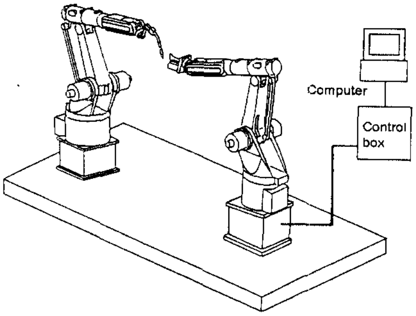

Fig. 1 Robot System For Coordinated Motion

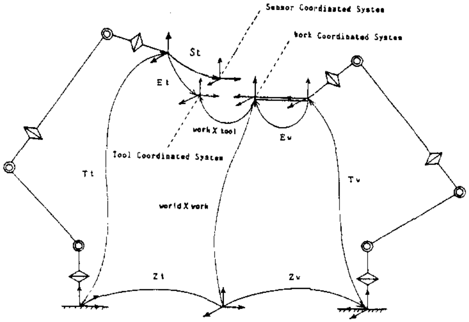

Fig. 2 Coordinated System

based on the baseplane of the tool manipulator using eq.(1).

Process 24 calculates the homogeneous transformation matrix $(T_w)_i$ representing the position and orientation of the workpiece attachment based on the baseplane of the workpiece manipulator using eq.(2).

Process 25 calculates the respective joint variables the tool manipulator by performing an inverse kinematics for $(T_t)_i$.

Process 26 calculates the respective joint variables the workpiece manipulator by performing an inverse kinematics for $(T_w)_i$.

Process 30 waits the synchronizing signal.

Process 31 specifies control signal of the servo-motors.

Above procedures are repeated until the (j+1)-th teaching point is arrived. Once the (j+1)-th teaching point is arrived, the next movement from the (j+1)-th teaching point to the (j+2)-th teaching point are performed. This procedures are shown in Fig 4.

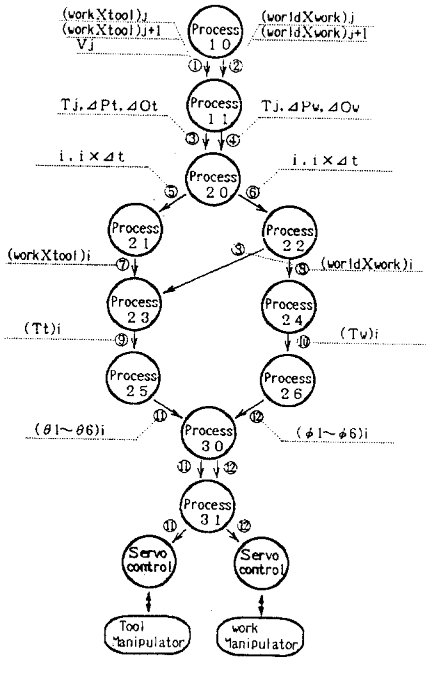

Fig 4. Task Graph of Playback

3 Introduction of Vision Sensor

Our teaching playback robot system enables the coordinated motions on the conventional industrial robots. However, because of the additional effects of the mechanical error on the two robots during the coordinated motion ,the number of the teaching points which is required to give accurate coordinated motion increases inevitably. Here we consider the vision sensor so that the number of the teaching points can be decreased. Our main concern here is about the welding tasks on the V shaped welding groove.

3.1 Configuration of Vision Sensor

Our vision sensor is composed of two semi-conductor laser emitters to project two pararell slit-rays, one CCD TV camera and an image processing computer. This sensor is mounted on the tip of the robot hand which holds a welding torch, The principle of the 3-dimensional measuring depends on the trigonometry. Two laser emitters are introduced so that the 3-dimensional position and posture of the target groove can be measured without scanning the laser light

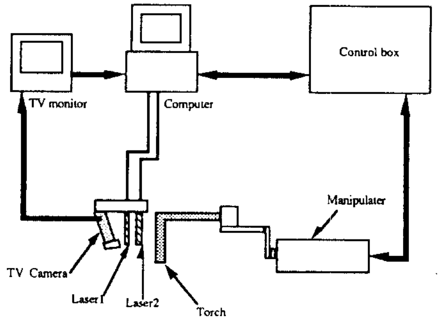

Figure 5. the Configuration of vision sensor

3.2 Data processing of the vision sensor

Data processing of the vision sensor are divided into two parts. First one is to detect the two points and four vectors. These data represent the geometrical features of the target groove.Considering the effects of the hazardous external lights, the data are obtained as follows:

Step1: One of the laser emitters is activated and the slit-ray image is stored in the memory.

step 2: The other laser is activated and the slit-ray image is subtracted from the previous memory. Due to the above steps the effects of the hazardous external lights are omitted. Resultant image is shown in Fig. 5 where Line A is the slit-ray image of the first laser emitter and Line B is of the second laser emitter.

Step 3: Estimated bottom points of the grooves on the both lines are detected. They are denoted B_1 and B_2 in Fig.6

Step 4: Line fitting with the least-squared error is performed on the both side of estimated bottom points B_1 and B_2.

(world): The world coordinate system of both robots.
(work): The work coordinate system settled at one reference point on the workpiece.
(tool): The tool coordinate system settled at the tip of the welding torch.
(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_w): Homogeneous transformation matrix of the gripper.
(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.
(S_t): Homogeneous transformation matrix of the sensor.

2.1 Algorithm

Considering the relation between the tool and workpiece manipulators,we obtain

$$({}^{world}X_{tool}) = ({}^{world}X_{work})\,({}^{work}X_{tool}) \qquad (1)$$

Therefore, we can find the $({}^{work}X_{tool})$ from the following equation.

$$({}^{work}X_{tool}) = ({}^{world}X_{work})^{-1}\,({}^{world}X_{tool}) \qquad (2)$$

2.2 Teaching of Task

By using teach pendant, the operator moves the torch and workpiece manipulators. When the operator requests the control system to record the j-th position and the orientation of the robots, the control system calculates the homogeneous transformation matrix $({}^{work}X_{tool})_j$ and $({}^{world}X_{work})_j$. After that,these two matrices are stored in the memory as teaching data. It should be noted that the homogeneous transformation matrix $({}^{work}X_{tool})$ is stored instead of $({}^{world}X_{tool})$, since relative positions and orientations between the torch and the workpiece are main concerns in the coordinated motions.

2.3 Playback of Task

Once all teaching data are obtained, we can playback all the movement considering welding speed that is also specified during the teaching task. Here, we explain how to playback the movement between the j-th and (j+1)-th teaching points. Playback of pre-specified movements needs calculating linearly interpolating points between every teaching point, since the teaching points are not enough to give smooth movements, as shown in Fig. 3.

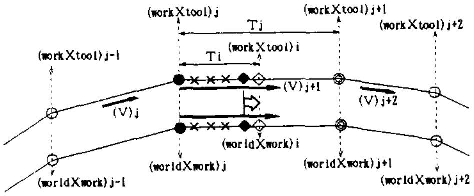

Fig. 3. Playback Task

2.4 Control method for the Coordinated motion

The motion of the torch and the workpiece are controlled coordinately according to the teaching data. Here, we summarize the procedures to realize the coordinated motion between j-th and (j+1)-th teaching points. The procedures are divided into small processes so that parallel processing technique can be easily adopted to this controlling procedure. Fig. 4 shows the relation of the every process and the data flow. The functions of every process are as follows;

Process 10 fetches the j-th and (j+1)-th teaching data. These data consist of the tool position and orientation based on the workpiece coordinate system $({}^{work}X_{tool})$, and the work position and orientation based on the world coordinate system $({}^{world}X_{work})$, and the tool speed V based on the workpiece coordinate system.

Process 11 calculates the total time Tj of translational movement of tool based on the workpiece coordinate system.A parameter i representing the serial number of the interpolating point is reset to zero.

Process 20 increase a parameter i and get the interpolating time $T_i(= dt^*{}_i)$.

Process 21 calculates the homogeneous transformation matrix $({}^{work}X_{tool})_i$ representing the tool position and orientation based on the work coordinate system.

Process 22 calculates the homogeneous transformation matrix $({}^{world}X_{work})_i$ representing the work position and orientation based on the world coordinate system.

Process 23 calculates the homogeneous transformation matrix $(T_t)_i$ representing the position and orientation of the tool attachment

Step 5: From these four lines we obtain improved estimated bottom points C_1 and C_2 These C_1 and C_2 points are obtained as the crossing points of four lines obtained the above.

Step 6: On the above four lines, we obtain four points P_1, P_2, P_3 and P_4. These four points are selected so that the vertical distance on the raster coordinates becomes pre-determined value.

Step 7: The raster coordinates of points C_1, C_2, P_1, P_2, P_3 and P_4 are transferred to the corresponding 3-dimensional coordinates.

Step 8: From the 3-d coordinates of P_1-P_4 we obtain the unit vector $V_i(i=1,2,3,4)$ to represents the gradients of the side walls of the grooves.

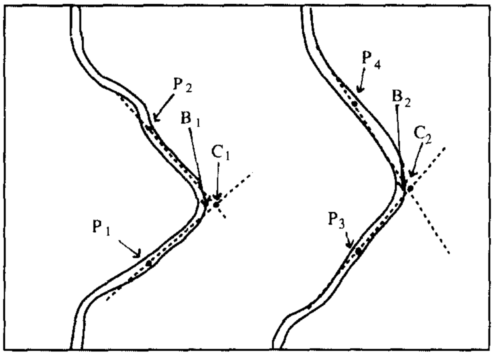

Fig. 6 Slit-Ray Image

The above steps give two points and four vectors to represent the 3-dimensional features of the target groove. Next part of the data processing is to determine the 3-dimensional position and posture of the target groove. Here we suppose that the 3-dimensional shape of the target groove around the point C_1 can be approximated with the two surfaces generated by the linear combination of the vector V_1 and V_3 and also that of the vector V_2 and V_4.

In order to represent the 3-dimensional posture and position of the target groove, we define the target coordinate system, where the x axis coincident with the line C_1C_2 and the angle between the y axis and V_1+V_2 becomes ninety degrees.

The geometrical relation gives the following homogeneous transformation matrix:

$$M_s=\mathrm{Trans}(0,Y_{c1},Z_{c1})\mathrm{Rot}(Z,\alpha)\mathrm{Rot}(Y,\beta)\mathrm{Rot}(X,\gamma) \tag{3}$$

where notations come from Denavit Hartenberg,(X_{ci},Y_{ci},Z_{ci}) are the coordinates of point C_i and the angles are obtained by;

$$\alpha = \tan^{-1}((y_{c2}-y_{c1})/(z_{c2}-z_{c1}))$$

$$\beta = \tan^{-1}(-\sin((y_{c2}-y_{c1})/(z_{c2}-z_{c1})))$$

$$\gamma = \tan^{-1}\left(\frac{(V_{1y}+V_{2y})\cos(\beta)}{((V_{1y}+V_{2y})\sin(\beta)\sin(\alpha)+(V_{1y}+V_{2y})\cos(\alpha))}\right)$$

(V_{ix},V_{iy},V_{iz}): coordinates of vector V_i (4)

The above matrix represents the 3-dimensional position and posture of the target groove with respect to the sensor coordinate system.

This matrix can be determined by the image processing of the sli-ray images.

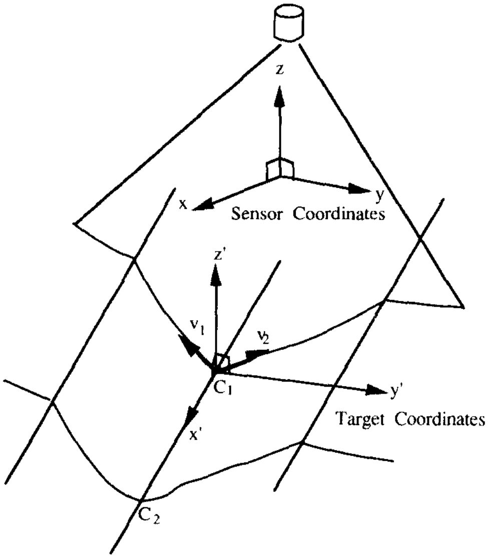

Fig.7 Sensor and Target Coordinate System

3.3 Compensation of teaching data

Using the vision sensor, we can decrease the number of the required teaching points. Suppose that two teaching points P_i and P_{i+1} are specified on the target groove by the operator. If the groove is almost straight during these two points, these two points are satisfactory . However, if the groove between these two points is curved, substitution of teaching points is required. Our system enables the substitution of teaching points using the vision sensor, if teaching points are not enough for the robots to trace the target groove. Since our system substitutes the teaching points automatically and also adjusts the posture and the position of the robots, the operator is not required to teach the target points with the intensive attention. In Fig.8 we represents the relation of the coordinate systems concerning to the sensor and the welding torch and the target groove. where Es means the homogeneous transformation matrix of the sensor.

The geometrical relatiuon gives

$$({}_{work}X_{target})=({}_{work}X_{tool})E_t^{-1}\,E_s\,M_s \tag{5}$$

Since our concern is to compensate the robot movement so that the output data M_s becomes the desired value M_s^* as much as possible. The desired value M_s^* can be obtained by the vision sensor. One reasonable M_s^* might be the average value of the data obtained at P_i and P_{i+1}. Usually the output data of the vision sensor differs from the ideal value. However, following the n-th movement of the robots, if the robots are moved so that the matrix $({}_{work}X_{tool})$ satisfies the following equation;

$$({}_{work}X_{tool})E_t^{-1} E_s M_s = ({}_{work}X_{tool})_n E_t^{-1} E_s M_s \qquad (4)$$

the output of the vision sensor agrees with M_s^*, where $({}_{work}X_{tool})_n$ represents the 3-dimensional posture and the position realized by the n-th movement.

Here we denote $({}_{work}X_{tool})=(C)_n({}_{work}X_{tool})_n$. Then, the following relation is obtained;

$$(c)_n = ({}_{work}X_{tool})_n E_t^{-1} E_s M_s (M_s^*)^{-1} ({}_{work}X_{tool})_{n-1} \qquad (5)$$

This matrix represents the required correction of the 3-dimensional relation between the work and the welding torch to attain the desired M_s^*. As you notice, the matrix $(C)_n$ becomes unity if M_s equals to M_s^*.

Considering the above relation, we employed a control method which is shown in Fig.9

One feature of this method is that the correcting matrix $(C)_n$ is determined by the data obtained at the previous n-1 th movement.

Following the above method, our robot system enable to track the target groove between P_i and P_{i+1}. During these tracking tasks, data $(C)_n$ are stored in the memory. After the tracking between P_i and P_{i+1}, substitution of teaching points are performed considering matrix $(C)_n$.

By using our method, the teaching task of the operator can be simplified remarkably.

4 Conclusion

This paper has been presented the welding robot with the coordinated motion.Our system mounted the vision sensor based on the light-section method. By this vision sensor we reduced a number of teaching data and improved the performance of the welding. Experimental results show that a number of teaching data is reduced 20% and that the welding error keeps less than 1 [mm].

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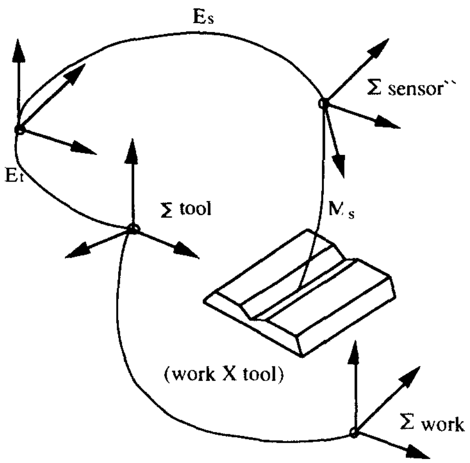

Fig. 8 Relation of Coordinates

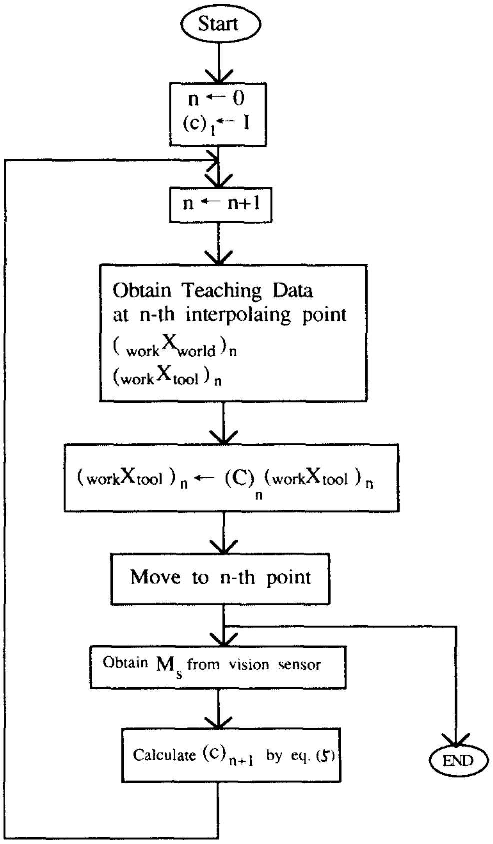

Fig.9 Control Scheme of Robot