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A 5-DOF Combined Robot Platform for Automatic 3D Measurement

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Abstract. This paper describes the reconstruction process of a 3P2R type combined robot platform on the basis of a 2-axis linearly moving worktable. An additive 3-DOF manipulator installed above the worktable has one prismatic and two revolute joints by using a novel integrated ball screw and spline axis. The control system of the platform is composed of a 4-axis motion control card and a PLC. Meanwhile, this paper deduces the kinematic equations of this special combined platform for measurement. The 3P2R type platform could be used to measure 3D contour of small work piece automatically.

Introduction

When detecting the geometric parameters of one work piece, a coordinate measuring machine (i.e. CMM) [1] is usually used to inspect the corresponding feature points on the contour of the piece with high precision. In the field of 3D measurement for reverse engineering, laser range finder based non-contact measuring method is more universal and efficient. However, these special measurement devices are very costly. Another way is to use industrial robot with sensor to replace CMM [2]. It depends on the level of openness of the robot controller.

In order to make a balance between cost and performance, this paper designs a 5-DOF robot platform for 3D measurement, which integrates the advantages of linearly moving worktable and SCARA robot [3]. The following sections will present the mechanism, control and kinematics of this novel robot in detail.

Mechanical Structure of 3P2R Robot

X-Y Moving Worktable. The worktable is driven by two servo motors with the mechanism of ball screw, which produces linearly in x and y directions. By using interpolation algorithm, the worktable could move with complicated trace in the horizontal plane. Fig. 1 shows this worktable.

1P2R Manipulator. Based on the X-Y linearly moving worktable, a 3-DOF manipulator is designed for the application of automatic measurement. This manipulator is mainly made up of a ball screw and spline axis. By rotating the ball screw bearing and the ball spline bearing with a designated rule [4], the axis could do basic movements including vertical moving and rotating around the vertical axis. Moreover, a horizontal rotating axis is added at the bottom of this vertical axis. This horizontal axis is driven by a servo motor on the top of this vertical axis. Therefore, this manipulator is 1P2R type mechanism, which is shown in Fig. 2.

The 2-axis worktable has two prismatic joints in x, y directions. And the manipulator has one prismatic joint and two revolute joints. By combining the X-Y worktable and the 3-DOF manipulator, the robot platform has five 3P2R type movements. The corresponding joint variables are shown in Table 1.

Fig. 1 The X-Y worktable

Fig. 2 The 1P2R manipulator

Table 1 The joint variables of the robot platform

Robot	Joint variable	Zone
X-Y worktable	d_x	0~500mm
	d_y	0~500mm
	d_z	0~300mm
1P2R manipulator	θ_2	–180~+180º
	θ_3	–120~+120º

Control System Design

The original control system of the X-Y moving worktable used a 4-axis motion control card in an industrial PC. The model number of the card is Googol GT-400-PCI-12 [5], which could only control four servo motors simultaneously. So the two motions of the 3-DOF manipulator are controlled by this card additionally. Now a Siemens S7-1200 PLC [6] is added to control the horizontally rotating axis of the manipulator specifically. The PLC communicates with the PC by using the hardware and software interfaces of Ethernet and OLE for Process Control (i.e. OPC) respectively. The schematic frame of the control system is shown in Fig. 3. In order to control the 5-DOF robot platform reasonably, motor 1 and 2 of the ball screw and spline axis must be driven simultaneously, so do motor 4 and 5 of the X-Y worktable.

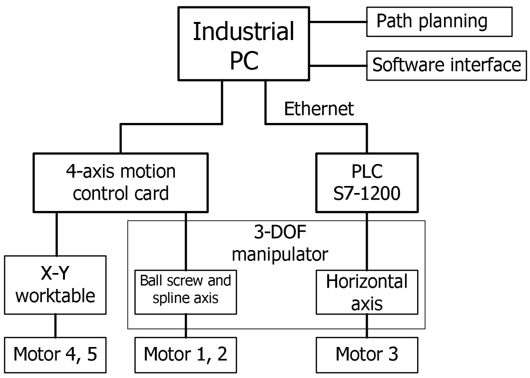

Fig. 3 Diagram of the robot's control system

Robot Kinematics for Measurement

In order to represent the relationship between the joint variables and the end-effector's pose, a series of coordinates are built one by one. In Fig. 4, $O_0x_0y_0z_0$ represents the world coordinates. $O_1x_1y_1z_1$, $O_2x_2y_2z_2$ and $O_3x_3y_3z_3$ represent the joint coordinates on the manipulator. And the origin points O_2 and O_3 are overlapped. These coordinates are built according to the Denavit-Hartenberg Method [7]. $O_mx_my_mz_m$ represents the coordinates of the end-effector. In addition, $O_4x_4y_4z_4$ represents the coordinates on the X-Y moving table.

According to the world coordinates and the joint coordinates, the homogeneous transformation matrices between the adjacent coordinates are calculated as below.

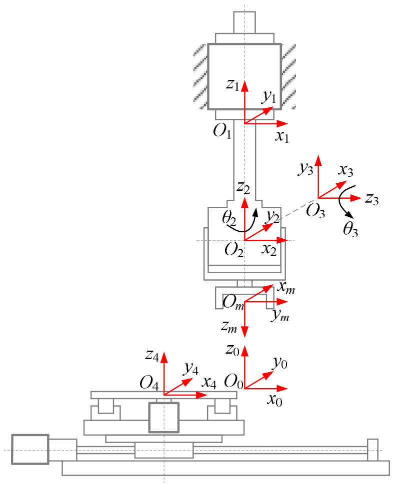

Fig. 4 The coordinates of the robot platform

$$
{}^{0}\mathbf{A}_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_z + Z_{off} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^{1}\mathbf{A}_2 = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 0 \\ \sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^{2}\mathbf{A}_3 = \begin{bmatrix} 0 & 0 & 1 & 0 \\ \cos\theta_3 & -\sin\theta_3 & 0 & 0 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}
$$

In these matrices, d_z, θ_2 and θ_3 represent the joint variables of the manipulator. Z_{off} is the offset distance between the origin points O_1 and O_0. When $d_z = 0$ and $\theta_2 = 0$, the coordinates $O_1x_1y_1z_1$ and $O_2x_2y_2z_2$ are overlapped. If the distance between the center of the end-effector and the origin point O_3 is denoted as L_m, then the corresponding transformation matrix is

$$
{}^{3}\mathbf{A}_{\mathbf{m}} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & -L_m \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}
$$

The compound homogeneous transformation matrix is denoted as ${}^{0}\mathbf{A}_{\mathbf{m}}$.

$$
{}^{0}\mathbf{A}_{\mathbf{m}} = {}^{0}\mathbf{A}_1 \cdot {}^{1}\mathbf{A}_2 \cdot {}^{2}\mathbf{A}_3 \cdot {}^{3}\mathbf{A}_{\mathbf{m}} = \begin{bmatrix} -\sin\theta_2\cos\theta_3 & \cos\theta_2 & -\sin\theta_2\sin\theta_3 & -L_m\sin\theta_2\sin\theta_3 \\ \cos\theta_2\cos\theta_3 & \sin\theta_2 & \cos\theta_2\sin\theta_3 & L_m\cos\theta_2\sin\theta_3 \\ \sin\theta_3 & 0 & -\cos\theta_3 & d_z + z_{off} - L_m\cos\theta_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}
$$

Another homogeneous transformation matrix ${}^{0}\mathbf{A}_4$ shows the relationship between the coordinates $O_4x_4y_4z_4$ and the world coordinates.

$$
{}^{0}\mathbf{A}_4 = \begin{bmatrix} 1 & 0 & 0 & d_x + X_{off} \\ 0 & 1 & 0 & d_y + Y_{off} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}
$$

Here, X_{off} and Y_{off} are the offset distances between the origin points O_4 and O_0. If there is one point ${}^{4}\mathbf{p}$ with normal vector $\mathbf{n}$, orientation vector $\mathbf{s}$ and approach vector $\mathbf{a}$ in the coordinates $O_4x_4y_4z_4$, and ${}^{4}\mathbf{p} = ({}^{4}p_x, {}^{4}p_y, {}^{4}p_z)^{\mathrm{T}}$, the transformation matrix is:

$$^{4}\mathbf{T_p} = \begin{bmatrix} \mathbf{n} & \mathbf{s} & \mathbf{a} & ^{4}\mathbf{p} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

Then this point's transformation matrix in the world coordinates is:

$$^{0}\mathbf{T_p} = {}^{0}\mathbf{A}_4 \cdot {}^{4}\mathbf{T_p} = \begin{bmatrix} \mathbf{n} & \mathbf{s} & \mathbf{a} & \mathbf{p} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

In the matrix on the right equation above, vector $\mathbf{p} = ({}^{4}p_x + d_x + X_{off}, {}^{4}p_y + d_y + Y_{off}, {}^{4}p_z)^{\mathrm{T}}$.

If the end-effector reaches this point with corresponding pose, there is an equation between 0Am and 0Tp as below.

$$\begin{bmatrix} -\sin\theta_2\cos\theta_3 & \cos\theta_2 & -\sin\theta_2\sin\theta_3 & -L_m\sin\theta_2\sin\theta_3 \\ \cos\theta_2\cos\theta_3 & \sin\theta_2 & \cos\theta_2\sin\theta_3 & L_m\cos\theta_2\sin\theta_3 \\ \sin\theta_3 & 0 & -\cos\theta_3 & d_z + z_{off} - L_m\cos\theta_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \mathbf{n} & \mathbf{s} & \mathbf{a} & \mathbf{p} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}$$

In the process of automatic measurement, the end-effector is vertical to the surface of the workpiece and moves along to the planned path. So the normal vector n and the approach vector a are known. Then θ2 and θ3 could be calculated.

Furthermore, a vector $\mathbf{p}' = ({}^{4}p_x + d_x + X_{off}, {}^{4}p_y + d_y + Y_{off}, {}^{4}p_z - d_z - Z_{off})^{\mathrm{T}}$ could be calculated, which determines the relationship between 4p and the vector of joint variables (dx, dy, dz)T. Finally, the combined robot platform could control the joint variables q = (dx, dy, dz, θ2, θ3)T to approach to each point above the worktable with designated pose.

Summary

This paper presents the design of 3P2R type combined robot platform for 3D measurement based on an X-Y moving worktable. The additive 3-DOF manipulator is a lower-mobility mechanism but is sufficient for 3D measurement. In the future work, a multi-axis motion controller will be used to increase the positioning accuracy and to realize synchronous control for more complicated mission.

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References

[1] X.C. Zhang: *Reverse Modeling Technique and Product Innovation Design*. (Peking University Press, China 2009). (In Chinese)
[2] A. Li, W. Wang and D. Wu: *Proc. IEEE International Conference on Robotics and Biomimetics* (Guilin, China, December 19-23, 2009). pp. 1361-1364.
[3] H. Makino and N. Furuya: Robotic Assembly, 1985, pp. 13-26.
[4] J. Hu and T. Zhang: Machine Tool and Hydraulics, Vol. 39 (2011), No.21, pp. 28-31. (In Chinese)
[5] Information on http://www.googoltech.com.cn
[6] Information on http://www.automation.siemens.com
[7] M.W. Spong, S. Hutchinson and M. Vidyasagar: *Robot Modeling and Control* (John Wiley & Sons, USA 2005), pp. 65-102.