Design and Experimental Report for the Special 3D.O.F Robot Manipulator

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Abstract: In recent years, robots have been used widely in industrial field and have been expanded as a result of continuous research and development for high-speed and miniaturization. The goal of this paper is to design the serial manipulator through kinematic analysis and to control the position and orientation of end-effector with respect to time. In general, a structure of industrial robot consists of several links connected in series by various types of joints, typically revolute and prismatic joints. The movement of these joints is determined in inverse kinematic analysis. Compared to the complicated structure of parallel and hybrid robot, open loop system retains the characteristic that each link is independent and is controlled easily.

AC servo motor is used to place the robot end-effector toward the accurate point with the desired speed and power while it is operated by position control algorithm. The robot end-effector should trace the given trajectory within the appropriate time. The trajectory of end-effector can be displayed on the monitor of general personal computer through Opengl program.

Keywords: Robot Manipulator, Jacobian, Static, Monitor program

1. Introduction

The motivation for this investigation is to construct a serial robot manipulator that fits the desired movement. The requirements are to cover the desired work with the given speed and power.

Handling and assembling applications with parallel robots were examined early in the robotics. Today many of them are employed in industrial application, for instance for the high speed pick and place operation. In comparison to serial robots, the reduced working space has brought out the fast development of robots in the serial systems. There is a defect that most of parallel robot manipulators should be operated by numerical method and need a lot of calculations.

Serial mechanism devices are utilized in relatively low payload to manipulator weight ratio tasks requiring low to medium accuracy and a large work volume. The disadvantage of serial robot should be reduced because the performance and power of actuator is improving more and more.

As you know well, hybrid structure manipulators exploiting the advantages of both fully parallel and serial mechanism can potentially be developed. Otherwise, the kinematic analysis of hybrid robot manipulator must be difficult and impossible with the conventional theory.

Eventually, we are trying to develop the serial robot manipulator for the appropriate characteristics. These characteristics include reasonable work volume, high stiffness, accuracy, payload to manipulator weight ratio and dynamic performance, and work volume performance characteristics.

2. Design of 3D.O.F Robot Manipulator

Fig.1 describes the schematic of the active robotic suspension. Using the Catia program, we can obtain it.

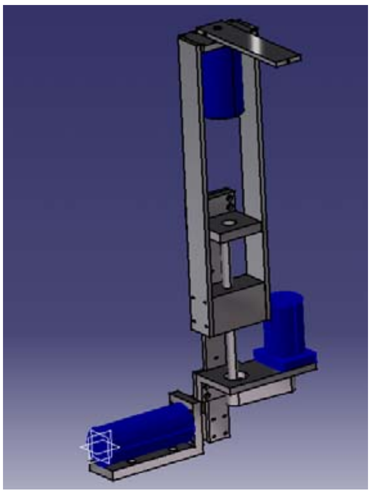

Fig. 1 Schematic of the 3D.O.F Robot Manipulator

2.1 Kinematics of 3D.O.F Robot Manipulator

2.1.1 Forward Kinematic Analysis

The robot manipulator consists of three links connected in series by two revolute joints and one prismatic joint. The first and third joints are revolute and the second joint is prismatic.

Table 1 D-H Parameters of the 3D.O.F Robot Manipulator

Joint i	θ_i	d_i	a_i	α_i
1	$\theta_1(t)$	d_1	0	-90°
2	0	$d_2(t)$	0	0
3	$\theta_3(t)$	0	$-a_3$	0

Here, table 1 shows the D-H Parameters of 3D.O.F robot manipulator.

The following parameter are uniquely determined by the geometry of the axes:

θ_i : joint angle between two incident normals of a joint axis

d_i : translational distance between two incident normal of a joint axis

a_i : offset distance between two adjacent joint axes

α_i : twist angle between two adjacent joint axes

For a robot to perform a specific task, the location of the end-effector relative to the base should be established first. This is called the position analysis problem. There are two types of position analysis problems: forward position or forward kinematics and inverse position or inverse kinematics problems. For forward kinematics, the joint variables are given and the problem is to find the location of the end-effector.

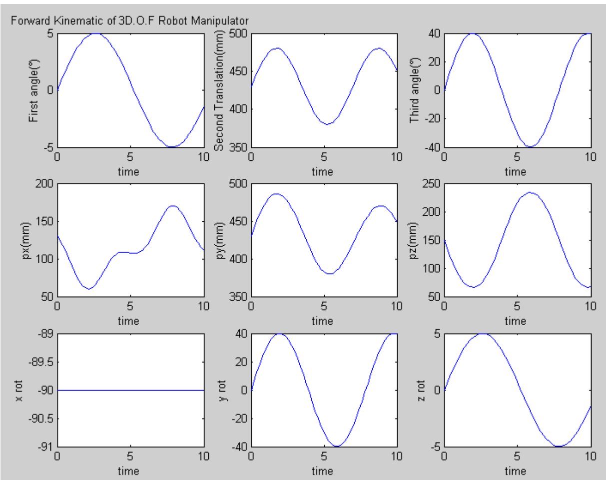

Fig. 2 Forward Kinematics of the 3D.O.F Robot Manipulator

Fig. 2 shows the forward kinematics of the 3D.O.F robot manipulator. The range of three actuators is determined arbitrarily. The first joint variable is $\pm 5^\circ$, the second joint variable is $\pm 50mm$, and the last joint variable is $\pm 40^\circ$.

2.1.2 Inverse Kinematic Analysis

In order to control the position and orientation of the end-effector of a serial robot manipulator, the inverse kinematics solution is more important. In other words, given the position and orientation of the end-effector of the robot and its joint and link parameters, we would like to find the corresponding joint angle of the robot so that the end-effector can be positioned as desired.

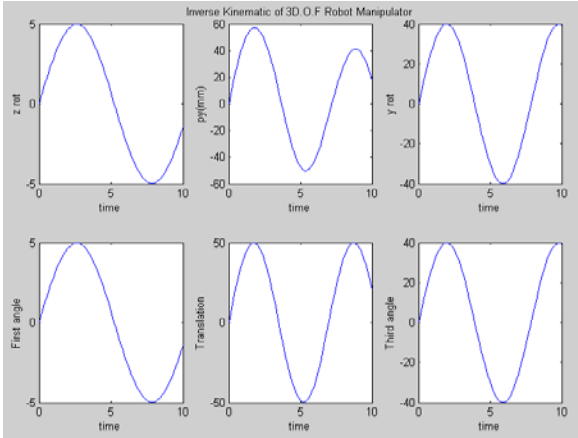

Fig. 3 Inverse Kinematics of the 3D.O.F Robot Manipulator

Figure 3 shows the inverse kinematics of the 3D.O.F robot manipulator. As shown in this figure, the result must be as same as the unknown input data of forward kinematic analysis.

2.2 Jocobian of 3D.O.F Robot Manipulator

For robot manipulators, the Jacobian is defined as the matrix that transforms the joint rates in the actuator space to the velocity state in the end-effector space. It is necessary to move the end-effector of a manipulator along some desired paths with a prescribed speed.

The velocity of end-effector can be written as,

$$\dot{x} = [v_{3x}, v_{3y}, v_{3z}, \varpi_x, \varpi_y, \varpi_z]^T \tag{1}$$

The velocity of three joints velocity can be written as,

$$\dot{q} = [\dot{\theta}_1, \dot{d}_2, \dot{\theta}_3]^T \tag{2}$$

The time derivatives of x can be written as a function of $\dot{q}$

$$\dot{\mathbf{x}} = J\dot{\mathbf{q}} \tag{3}$$

The jocobian matrix can be written as,

$$J = \begin{bmatrix} -\cos(\theta_1)d_2 - a_3\sin(\theta_1)\cos(\theta_3), & -\sin(\theta_1), & -a_3\cos(\theta_1)\sin(\theta_3) \\ -\sin(\theta_1)d_2 + a_3\cos(\theta_1)\cos(\theta_3), & \cos(\theta_1), & -a_3\sin(\theta_1)\sin(\theta_3) \\ 0, & 0, & -a_3\cos(\theta_3) \\ 0, & 0, & -\sin(\theta_1) \\ 0, & 0, & -\cos(\theta_1) \\ 1, & 0, & 0 \end{bmatrix} \tag{4}$$

2.3 Statics of 3D.O.F Robot Manipulator

Static force analysis is practical importance in determining the equality of force transmission through the various joints of a mechanism. It serves as a basis for sizing the links and bearings of a robot manipulator and for selecting appropriate actuators.

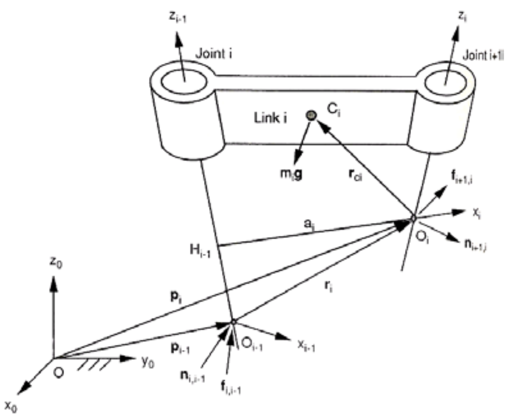

Fig. 4 Forces and Moments Acting on Link I

In a serial manipulator, each link is connected to one or two other links by various joints. Fig. 4 depicts the forces and moments acting on a typical link i that is connected to link $i-1$ by joint I and to link $i+1$ by joint $i+1$.

The following notations are defined:

$\mathbf{f}_{i+1,i}$: resulting force exerted on link $i+1$ by link I at $O_i, \mathbf{f}_{i,i+1} = -\mathbf{f}_{i+1,i}$.

$\mathbf{g}$: acceleration of gravity.

m_i : mass of link i.

$\mathbf{n}_{i+1,i}$: resulting moment exerted on link $i+1$ by link i, about point O_i, $\mathbf{n}_{i,i+1} = -\mathbf{n}_{i+1,i}$.

$\mathbf{r}_{ci}$: position vector of the center of mass of link i relative to the i th link frame (i.e., $\mathbf{r}_{ci} = \overline{O_i C_i}$).

$\mathbf{r}_i$: position vector of O_i with respect to the $(i-1)$ th link frame $(i.e.,\ \mathbf{r}_i = \overline{O_{i-1} O_i})$.

First we consider the balance of forces. As shown in Fig. 4, there are three forces exerted on link i.

Hence a force balance equation can be written as

$$\mathbf{f}_{i,i-1} - \mathbf{f}_{i+1,i} + m_i \mathbf{g} = \mathbf{0}. \quad (5)$$

Next, we consider the balance of moments about the origin O_i. There are two moments acting on link i : $\mathbf{n}_{i,i-1}$ and $-\mathbf{n}_{i+1,i}$. In addition, the two forces $m_i \mathbf{g}$ and $\mathbf{f}_{i,i-1}$ produce moments about O_i. Summing these moments together, we obtain

$$\mathbf{n}_{i,i-1} - \mathbf{n}_{i+1,i} - \mathbf{r}_i \times \mathbf{f}_{i,i-1} + \mathbf{r}_{ci} \times m_i \mathbf{g} = \mathbf{0} \quad (6)$$

where, ${}^i\mathbf{r}_i = \begin{bmatrix} a_i \\ d_i s\alpha_i \\ d_i c\alpha_i \end{bmatrix}$, $\mathbf{r}_{ci} = {}^0R_i\, {}^i\mathbf{r}_{ci}$, $\mathbf{r}_i = {}^0R_i\, {}^i\mathbf{r}_i$.

It is assumed that output force and moment are neglected and the center of mass is located at the midpoint of each link and the effect of gravity is considered. Also let the acceleration of gravity be pointing along the negative y_0-direction and. We can find the joint reaction forces and moments.

Table 2 Joint Force of 3D.O.F Robot Manipulator

	Fn			Mn		
	Fxn	Fyn	Fzn	Mxn	Myn	Mzn
1 joint	0 N	392 N	0N	-51.45N	0N	6.37N
2 joint	0 N	294 N	0N	0N	0N	6.37N
3 joint	0 N	98 N	0N	0N	0N	6.37N

It is assumed that output force and moment are neglected. Once the joints are located at the desired point, the joint reaction forces and moments can be calculated at that point.

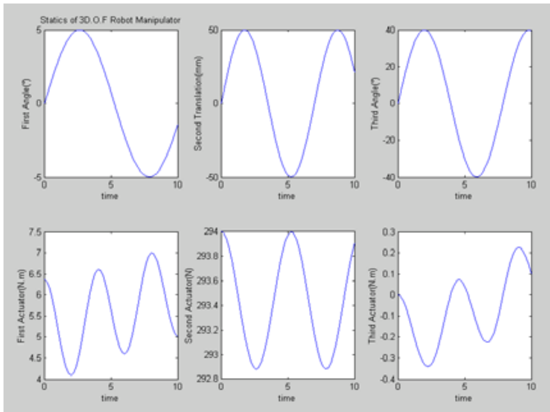

Fig. 5 Actuator Torque and Force of 3D.O.F Robot Manipulator

The reaction forces in the joints are known and the actuator forces or torques can be determined. For a serial manipulator, an actuator that exerts either a force or a torque between two adjacent links drives each joint. These actuator forces or torques can be found by projecting the reaction forces onto their corresponding joint axes.

For a prismatic joint, the actuator force is exerted along the i th joint axis. Assuming that frictional force at the joint is negligible, the actuator force,

$$\tau_i = \mathbf{z}_{i-1}^T \mathbf{f}_{i,i-1} \quad (7)$$

Similarly, for a revolute joint, the actuator exerts a torque instead of force about the i th joint axis. This actuator torque,

$$\tau_i = \mathbf{z}_{i-1}^T \mathbf{n}_{i,i-1}. \quad (8)$$

Where $\mathbf{z}_{i-1}$ is a unit vector pointing along the positive i th joint axis.

In order to convert the prismatic joint force into the motor torque, this equation is needed.

$$T = Q\tan(\alpha+\rho)\frac{de}{2} \tag{9}$$

Q : Axis force(kg)

α : Lead angle($^\circ$)

ρ : Friction angle of screw surface($^\circ$)

de : Diameter of screw(mm)

3. Software

3.1 Window Program

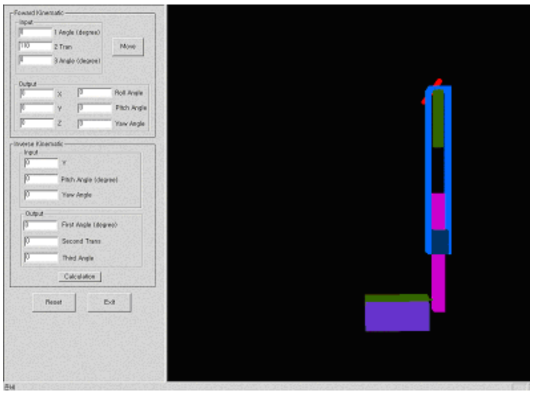

Fig. 5 Window Program of 3D.O.F Robot Manipulator

As shown in Fig. 5, the left diagram displays the icons that control the motion in forward kinematic analysis and determine the parameter of link length and angle.

Using the OpenGL program, we model the serial robot manipulator. Once the parameters are determined in dialogue box, movement of the robot is displayed on the monitor and we see the end-effector's trajectory in real space.

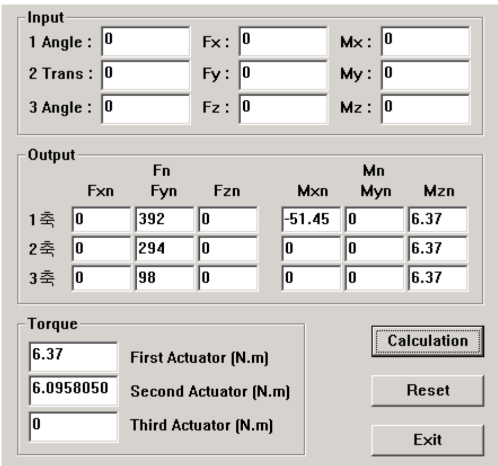

Fig. 6 Static Program of 3D.O.F Robot Manipulator

The reaction forces and moments at each joint are calculated with respect to the joint variable. Eventually, we find each joint torque to decide the performance of motor.

4. Equipment

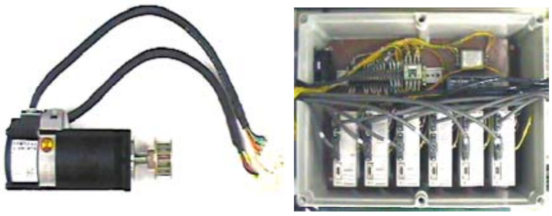

Fig. 7 Motor and Drivers of Equipment Device

We are trying to make the serial robot manipulator which consists of the Samsung AC servo motor, CSMZ-01BA1, and Panasonic AC servo motor, MFM042A1C. In the future, we input the sinewave function to the system and verify it.

5. Conclusion

An electric motor has linear characteristics and is more precise than a hydraulic actuator. So the electric motor is selected. A robot hand is attached to the last link of the three degrees of freedom hybrid robot manipulator. In order to possess these three motions that are z-axis rotation, y-axis rotation, and y-axis translation, the serial robot manipulator needs at least three actuators.

In this research, we design the bearing and link of the serial robot. We solve the static analysis and determine the performance of motor. Using the MMCBODPV81 which can do synchronous control, we control the AC servo motor of robot while the trajectory of the end-effector display on the monitor.

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