Kinematics analysis of a 3-DOF micromanipulator for Micro-Nano Surgery

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Abstract — **In this paper; we have analyzed a robotic system, which is used in micro-nano surgery. This robot is a parallel robotic system with 3 degree of freedom. The scale of this robot is millimeter. The special characteristic of robot is having an additional link, which connects the spherical joint to moving platform. Here kinematics analysis and Jacobean matrix are investigated. In the section II an introduction to micro-nano surgery is stated. Section III involves the kinematics analysis, and in section IV Jacobean matrixes are explained.**

Keywords — **Micro-nano surgery, Direct Kinematics analysis, indirect kinematics analysis, Parallel robot, Jacobean Matrix**

I. Introduction

Micro-nano surgery is a kind of surgery in which the operational tools are in millimeter, micro or even nanometer. These tiny tools are carried by robotic systems. This robotic system here is a parallel manipulator, which has 3 degree of freedom. This manipulator has been used for handling and precise positioning of micro object. It's function was successful. In this paper, we have done kinematics analysis and found Jacobean matrix.

II. Micro-nano surgery

Micro-Nano surgery is the medical branch of nanotechnology. It can be divided into two separate parts: 1- doing the operation by nano robots, and the second: doing the operation by making surgerical tools in micro-nano scales. In here, the micro-nano surgery belongs to second group. This surgery is done by a surgeon who guides the tools by using joy sticks and sees the operation via cameras. Because of the difficulty of handling these tiny equipments, robotic systems are used for this purpose. Most of the time the master-slave robotic systems are used. Micro-nano surgery has many advantageous:

- Because of the tiny scale of the operational tools, the lacerations are shallow and they will be recovered very soon, so the duration of hospitalization decreases and then the cost of treatment decreases too.
- The mistakes which are caused by surgeon's tiredness, hands tremor, not enough experience and vision will vanish. Because the surgeon will be laid in a comfortable place and will do the operation easily.
- The pain, stresses in patient will reduced as, in some cases there is no need to anesthetize the patient.
-This surgery is used in tele-operation mode, so there will not be many people in the surgery room, specially in disease with high infections.

However, there are some disadvantageous too:

- High cost of stall and handling robotic systems.
- Training surgeons
- A supervisor engineer must be there, in order to repair the robotic system in case of deficiencies.
- Making the operational tools in micro-nano scale, because every surgery needs its own equipment.

The most important contention in this surgery is compost of surgeon's experience with stability and exactitude of robot.

III. Kinematics analysis

The configuration of the robot is shown in the figure 1. This robot is made up of a prismatic joint which is in the base, then a revolute joint, and then a spherical joint. A special characteristic of this robot is the existence of an additional link, which connects the spherical joint to moving platform. This links make the analysis more complicated. The geometry parameters of the robot according to the fig.1 are:

r: the radius of upper plate

R: the radius of fixed plate

d_i: the length of kinematics chain

T: rotation matrix which its arrays are as below:

$\begin{bmatrix} n_1 & o_1 & a_1 \\ n_2 & o_2 & a_2 \\ n_3 & o_3 & a_3 \end{bmatrix}$, this matrix shows the direction of moving plate.

X-y-z Euler angles of α, β, γ .

Vector p $\begin{vmatrix} p_x \\ p_y \\ p_z \end{vmatrix}$ which connects the centroid of upper plate to the centroid of fixed one. This vector indicates the location of moving plate.

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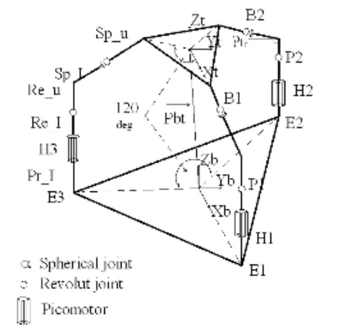

Fig.1 configuration of 3-PRS robot[2]

In direct kinematics analysis, the lengths of kinematics chains are known, and the purpose is finding position and orientation of moving platform. For this analysis, there are three groups of equations.

First group: equations which show the orthogonality of the matrix T. For this group we have 6 equations. These equations will be found in [1].

Second group: The revolute joint in all kinematic chains, imposes a constraint in moving. The second group equations are the constraints equations. Here 3 equations are got as:

$$P_y = -n_2 b_x + a_2 b_z \quad (1)$$

$$n_2 = O_1 \quad (2)$$

$$P_x = \frac{-1}{2}\left(O_2 b_x - n_1 b_x - 2a_1 b_z\right) \quad (3)$$

In which: b_x and b_z are the coordinates of spherical joints and are:

$$\begin{aligned} b_x &= r + sp\_u\cos\theta_{tr} \\ b_z &= SP\_U\sin\theta_{tr} \end{aligned} \quad (4)$$

Third group: These equations are related to the lengths of kinematic chains. The lengths of kinematic chains are found geometrically as:

$$\begin{aligned} d_1^{\,2} &= (p_x + n_1 b_x - a_1 b_z - R)^2 + (p_y + n_2 b_x - a_2 b_z)^2 \\ &+ (p_z + n_3 b_x - a_3 b_z)^2 \\ d_2^{\,2} &= (p_x - \frac{1}{2}n_1 b_x + \frac{\sqrt{3}}{2}o_1 b_x - a_1 b_z + \frac{1}{2}R)^2 + \\ &(p_y - \frac{1}{2}n_2 b_x + \frac{\sqrt{3}}{2}o_2 b_x - a_2 b_z - \frac{\sqrt{3}}{2}R)^2 + \\ &(p_z - \frac{1}{2}n_3 b_x + \frac{\sqrt{3}}{2}o_3 b_z - a_3 b_z)^2 \\ d_3^{\,2} &= (p_x - \frac{1}{2}n_1 b_x - \frac{\sqrt{3}}{2}o_1 b_x - a_1 b_z + \frac{1}{2}R)^2 + \\ &(p_y - \frac{1}{2}n_2 b_x - \frac{\sqrt{3}}{2}o_2 b_x - a_2 b_z + \frac{\sqrt{3}}{2}R)^2 + \\ &(p_z - \frac{1}{2}n_3 b_x - \frac{\sqrt{3}}{2}o_3 b_x - a_3 b_z)^2 \end{aligned} \quad (5)$$

For direct kinematics analysis, these 12 equations and 12 unknowns must be solved. But because of the nonlinearity of the equations, this is impossible and complicated. For this purpose we consider 2 Euler angels as knowns and find other parameters according to them. The table blow shows the result:

In all examples above, we considered the constant parameters as below:

$$R = 40mm$$
$$\theta = 5\deg ree$$
$$SP\_u = 5mm$$
$$r = 8mm$$
$$d = 100mm$$

$$b_x = 12.981mm$$
$$b_z = 0.43577mm$$

Tabel1-result of direct kinematics

α	β	T	P_x	P_y	P_z	γ
-3 degree	-3 degree	$\begin{bmatrix} -0/98992 & -0/00135768 & -0/14112 \\ 0/212725 & -0/989964 & -0/139708 \\ -0/139514 & -0/141311 & 0/980085 \end{bmatrix}$	-5.58025 mm	-78.9589, 83.4352 mm	-78.9589, 83.4352 mm	-0.0013741 degree
0 degree	0 degree	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	0 mm	9945.45, -9944.58 mm	9945.45, -9944.58 mm	0 degree
-3 degree	3 degree	$\begin{bmatrix} -0.989989 & 0.00271908 & -0.14112 \\ 0.0171957 & -0.990043 & -0.139708 \\ -0.140095 & -0.140736 & 0.980085 \end{bmatrix}$	-5.58023 mm	-78.9514, 83.4428 mm	-78.9514, 83.4428 mm	0.00274657 degree

The indirect kinematics analysis is much simpler than the direct one. In here the position and orientation of moving platform is known and the kinematic chains' length must be found. This can be easily done by equations (5). All analyses are done by "MATHEMATICA "software.

IV. JACOBEAN MATRIX

By Jacobean matrix the relations of velocities of moving platform and the joints or kinematic chains can be expressed. For this robot system, the input velocity is $\dot{q}$, which equals to $\dot{q} = [\dot{d}_1, \dot{d}_2, \dot{d}_3]$. The output velocity can be stated according to the velocity of the centroid of moving platform. A linear and an angular are considered as below" $\dot{x} = \begin{bmatrix} v_P \\ w_p \end{bmatrix}$. The Jacobean matrix is found from fig.2. An equation can be written based on vectors law:

$$\overline{OP} + \overline{Pb_i} = \overline{OE} + \overline{Eb_i} \tag{6}$$

By differentiating with respect to time form equation (6), the velocity is obtained:

$$V_P + w_P \times b_i = d_i w_i \times s_i + \dot{d}_i s_i \tag{7}$$

In the equation (7) b_i indicates the vector PB_i, s_i a unit vector in the direction of kinematic chains, w_i the angular velocity of i^{th} kinematic chain. The w_i is produced by the revolute joint, which is a passive joint and imposes constraint. So this velocity must be omitted form the equation. For this purpose, we do dot product the equation (7) by s_i. Then the equation becomes:

$$s_i . v_P + (b_i \times s_i) . w_p = \dot{d}_i \tag{8}$$

By writing the equation (8) three times, for all kinematic chains, the Jacobean matrix can be extracted:

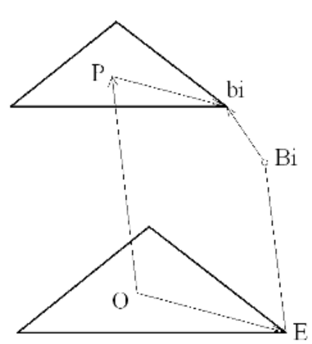

Fig.2 relation according to vectors law

$$\begin{aligned} &i=1 \quad s_1 . v_p + (b_1 \times s_1) . w_p = \dot{d}_1 \\ &i=2 \quad s_2 . v_p + (b_2 \times s_2) . w_p = \dot{d}_2 \\ &i=3 \quad s_3 . v_p + (b_3 \times s_3) . w_p = \dot{d}_3 \end{aligned} \tag{9}$$

then the Jacobean matrixes will be :

$$J_x = \begin{bmatrix} S_1^T & (b_1 \times s_1)^T \\ S_2^T & (b_2 \times s_2)^T \\ S_3^T & (b_3 \times s_3)^T \end{bmatrix}_{3\times 6} \tag{10}$$

$$J_q = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}_{3\times 3} \tag{11}$$

In which Jacobean matrix J_x is called the direct kinematics Jacobean, and the J_q is called the inverse kinematics Jacobean matrix. If the robot is not in the singular configuration, the total Jacobean matrix will be as :

$$J = J_q^{-1} J_x \tag{12}$$

And the relation between the velocities is :

$$\dot{q} = J\dot{x} \tag{13}$$

The Jacobean matrix can be used in static, stiffness analysis. It is also used for finding the singularity points for a robot.

V. CONCLUSIONS

In the Inverse Displacement Solution (IDS), the position of actuators, according to the movement of platform is found. In the Forward Displacement Solution (FDS), position and orientation of the moving platform is determined, while the position of actuators is known. FDS analysis is very complicated and it is used in calibration, it is not used in control problems of robot. In the kinematics analysis these results are gained:

1- p_z is the only independent parameter among the six parameter [p_x p_y p_z α β γ]. This parameter did not appear in the constraint equations, which means it can be chosen separately from five other parameters, and also choosing these five parameters is completely independent from p_z.

2- Although this mechanism has 3 degree of freedom, but we can't assume all three angle Euler as given data. Just two from three angles must be known. Also for controlling the mechanism, three parameters must be chosen, that one of them must be p_z. The two other parameters must be chosen from five remained parameters.

3- For each couple (p_x , p_y), two couples of Euler angles are existed, (α , β) and (- α, - β).For each given angle γ, the same couples are also existed. In the other hand:

$$\gamma = f_1(\beta, \alpha) = f_1(-\beta, -\alpha)$$

$$P_x = f_2(\beta, \alpha) = f_2(-\beta, -\alpha)$$

$$p_y = f_3(\beta, \alpha) = f_3(-\beta, -\alpha)$$

It means that in every point in robot workspace, a couple of Euler angles prevail that has the same γ. Two other angels are both positive and negative.

References

1. Tsai, Lung-wen "Robot Analysis: the Mechanics of Serial and Parallel Manipulators", NewYork 1999.
2. Goo Bong Chung, Byung-Ju Yi, Il Hong Suh, Whee Kuk Kim, Wan Kyun Chung "Design and Analysis of a Spatial3-DOF Micromanipulator for Tele-operation" Proceedings of the 2001 IEEE/RSJ International Conference on Intelligent Robots and Systems Maui, Hawaii, USA, Oct. 29 - Nov. 03, 2001
3. Guilin Yangt, Ming Chen, Wee Kiat Lim, Song Huat Yeo, "Design and Kinematic Analysis of Modular Reconfigurable Parallel Robots" Proceedings of the 1999 IEEE International Conference on Robotics & Automation Detroit, Michigao May 1999.
4. Juan A. Carretero, Meyer A. Nahon, Ron P. Podhorodeski "Kinematics of a New High-Precision Three- Degree-of-Freedom Parallel Manipulator" Journal of Mechanical Design March 2008, Vol.130.
5. Robert L. Williams, Atul R. Joshi "Planar Parallel 3-RPR Manipulator" Proceedings of the Sixth Conference on Applied Mechanisms and Robotics December 12-15, 1999.
6. Damien Chablat, Phlippe Wenger, Ilian A. Bonev "Self Motions of a Spetial 3-RPR Planar Parallel Robot" Proceeding of 2006 IEEE International Conference on Robotics and Automation .
7. Xin-Jun Liu, Jinsong Wang, Jongwon Kim "Determination of the Link Lengths for a Spatial 3-DOF Parallel Manipulator "Journal of Mechanical Design March 2006, Vol.128.
8. Qingsong Xu, Yangmin Li "A Novel Design of a 3-PRC Translational Compliant Parallel Micromanipulator for Nanomanipulation" Robotica, 2006, Vol. 00.
9. Qingsong Xu, Yangmin Li "Kinematic Analysis and Optimization of a New Compliant Parallel Micromanipulator" International Journal of Advanced Robotic Systems, Vol. 3, No. 4, 2006.

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