Analysis of a Micro-Nano Manipulator for Tele-Operation

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Abstract- In this paper, we have investigated a robotic system, which is used in tele-operation. This robot is a 3-DOF parallel robot and its dimensions are milli-centi meter, and can be used for the micro-Nano surgery. We have analyzed the kinematics of the robot and have done a simulation to find the range of kinematic chains' length. These analyses have been done by 'MATHEMATICA' software.

Key words: tele-operation, direct kinematics, indirect kinematics, kinematic chains, micro-nanosurgery

1 Introduction

Micro-Nano surgery is a surgery which is done by micro-Nano scale surgerical tools. Because of the difficulty in handling such tiny instruments, these equipments will be carried by robotic systems. This surgery also belongs to tele-operation surgeries and has many advantages:

- Because this surgery is done in tele-operation mode, the number of people presenting in surgery room decrease, especially in surgeries with x-ray and in surgeries with high infections.
- Because of the tiny scale of surgerical tools, the lacerations will be small and shallow, the cure occurs very faster.
- The cost of therapeutics will decrease.

The surgeons do the operation by using some joy-sticks and see the operation through cameras.

Many surgeries belong to this surgery such as: MIS[1] (laparoscopic surgery, Urology, Gynecology), ophthalmic surgery, brain surgery, cardiovascular surgery. Although this kind of surgery is advantageous, it has some problems too, such as

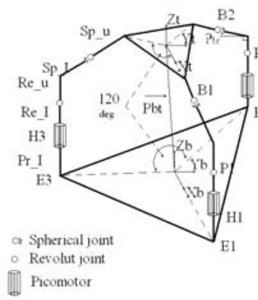
- Training surgeons
- manufacturing surgerical tools in tiny scales.
- Every surgery needs its own tools.

In this paper, we have worked on the robotic system which is used as slave system in handling micro objects. In section 2 the kinematics analysis is done, direct and indirect kinematics equations have been extracted. In section 3 we have done a simulation to find the range of each kinematic chain's length.

2 kinematics analysis

In the below, the configuration of the robot is seen.

[1] Minimally Invasive Surgery



2.1 Direct Kinematics

In the direct kinematics, the purpose is to find the location and orientation of moving platform, while the lengths of kinematic chains are known. For this purpose we have 3 kinds of equations. First the equations related to rotation matrix which are as below:

$$T = \begin{bmatrix} n_1 & o_1 & a_1 \\ n_2 & o_2 & a_2 \\ n_3 & o_3 & a_3 \end{bmatrix}, \text{ rotation matrix}$$

$n_1^2 + n_2^2 + n_3^2 = 1$ (1)
$o_1^2 + o_2^2 + o_3^2 = 1$ (2)
$a_1^2 + a_2^2 + a_3^2 = 1$ (3)
$n_1 o_1 + n_2 o_2 + n_3 o_3 = 0$ (4)
$n_1 a_1 + n_2 a_2 + n_3 a_3 = 0$ (5)
$o_1 a_1 + o_2 a_2 + o_3 a_3 = 0$ (6)

The second equations are constraint equations which we have obtained as below:

$P_y = -n_2 b_x + a_2 b_z$ (7)
$P_x = -0.5(o_2 b_x - n_1 b_x - 2 a_1 b_z)$ (8)
$n_2 = o_1$ (9)

in which :

p_x , p_y are coordinate of moving platform centroid , which determines the location of that plate.

b_x , b_z are the coordinates of spherical joints in moving coordinate system.

And finally the third equations are the length of kinematic chains, which we have obtained according to the geometry of robot and these lengths are as below:

$d_1^2 = (P_x + n_1 b_x - a_1 b_z - R)^2 + (P_y + n_2 b_x - a_2 b_z)^2 + (P_z + n_3 b_x - a_3 b_z)^2$ (10)

$d_2^2 = (P_x - 0.5 n_1 b_x + 0.87 o_1 b_x - a_1 b_z + 0.5R)^2 + (P_y - 0.5 n_2 b_x + 0.87 n_2 b_x - a_2 b_z - 0.87R)^2 + (P_z - 0.5 n_3 b_x + 0.87 o_3 b_x - a_3 b_z)^2$ (11)

$d_3^2 = (P_x - 0.5 n_1 b_x - 0.87 o_1 b_x - a_1 b_z - 0.5R)^2 + (P_y - 0.5 n_2 b_x - 0.87 n_2 b_x - a_2 b_z + 0.87R)^2 + (P_z - 0.5 n_3 b_x - 0.87 o_3 b_x - a_3 b_z)^2$ (12)

R is the radius of fixed plate.

In the equations above the unknowns are the components of matrix T and three component of vector $P(P_x, P_y, P_z)$. Solving these 12 equations in parametric mode is impossible, because of non-linearity of the equations. We solved the problem numerically by consuming the two of Euler angels known and finding the other unknowns according to that. One of these examples is brought below:

Example- Here we assume that the moving platform has a 3 degree rotation about x-axis and 3 degrees of rotation about y-axis. According to the dimensions of robot T matrix becomes:

$$\begin{bmatrix} -0.989992 & -0.001357 & 0.14112 \\ 0.212725 & -0.9899 & 0.139708 \\ 0.139514 & 0.141311 & 0.980085 \end{bmatrix}$$

and $P_x = -2.6917$ mm
$P_y = 2.57626$ mm
$P_z = -76.52335$ mm and 112.895 mm

2.2 Inverse kinematics

In indirect kinematics, the purpose is to find the length of kinematic chains, while the position and orientation of the moving platform is known. It is simply solvable by equations (10),(11),(12). Here, also a numerical example is solved.

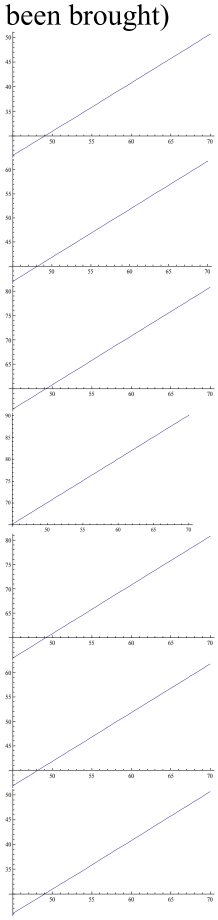
Example- In the previous case, with the known Matrix T and vector P, the length of kinematic chains become as below:

$d_1 = 52.485$, $d_2 = 51.9125$, $d_3 = 49.993$ mm.

All of these analysis are done by 'MATHEMATICA' software.

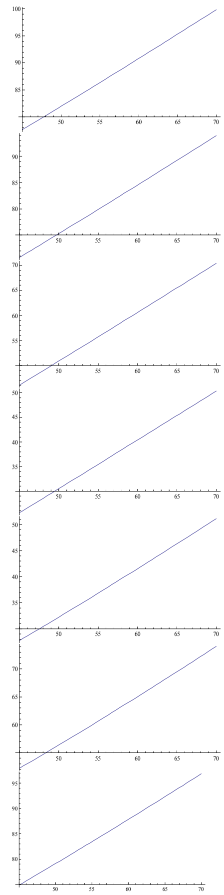
3 Simulation of length

In this section, the range of length changing, in two special motions are simulated. The first motion is the rotation of moving platform about axes y and z and the arbitrary angle of rotation about x-axis. The rates of changing of the first length are plotted in steps of the angles of rotation: (the other plotted haven't been brought)



This yields that the first kinematic chain, d1 is changing between 26-90 mm, the second one changes between 26-92 mm and the third kinematic chain changes between 26096 mm.

In the second case of motion, we assume rotations about x and z axes and an arbitrary angle about y axis. In this case, the lengths changing of the first kinematic chains have been brought. The plots are in angles steps.



According to the simulations, the rate of changes in first kinematic is between 26-100 mm, for the second one 25-90 mm and for the third kinematic changes are between 25-93 mm.

4 conclusions

In kinematic analysis, it's found that the P_z is not appeared in constraint equations, so it can be chosen freely. Its choosing is completely apart from the other five parameters.

Although the system has 3 DOF, but just two of three Euler angles can be chosen. Choosing all the three Euler angles together is not possible. The robot has a unique shape, because the spherical joints are connected to moving platform by an additional links, which make the equations even more complicated than other parallel robot even with higher DOFs. The length simulation is very useful, because this system is a tele-operation system and it is important for such systems that have a precise positioning.

References

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