Design Controller and Fibrication of 5R Parallel Robot For biopsy operation

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Abstract: - Todays, robots are used instead of labors in dangerous environments for long term by more accuracy. Some of them are made as serial arms and rest of them has parallel, configuration. In design of robot, after main configuration, kinematic and dynamic analysis are main steps. By having them controller design is possible. Also, kinematic inverse and dynamic inverse analysis is essential for main processes. parallel robots are employed widely in many applications due to their properties related to geometry. 5R robot is one of them which is utilized in sorting and engraving. Current paper presents a PI controller for this robot which was designed by coupling SolidWorks and MATLAB software to simulate kinematic of robot. It will be used in medicine injection in next work. Finally, a test rig of robot was fabricated in lab for accuracy assessment. It includes two servomotors which is controlled by Arduino as DAQ. The stability of robot in terms of trajectory control was reach properly.

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1. Introduction

Robots are designed and used widely in many areas. They must be robust, accurate and reliable]1[. A new application of robot is employing them in medical operations. Due to accuracy of robots, they can be used in biopsy, needle interventions, surgery etc. Two types of mechanisms are employed for robot design; closed chain and open chain mechanism. The stiffness is low in open chain robots, and required torque is high]2[. In opposite of serial robots, parallel robots are used without stated disadvantages [3-5]. Some investigations were carried out to develop parallel robots]6-8[. In addition, payload capacity, stiffness and stability are higher in parallel manipulators, but singularity is important in this case]8-10[.

Cancer is disease which early diagnosis of that is very important to solve problem, and precise drug delivery and biopsy of suspected tissue is vital issue. By biopsy sampling, a piece of target tissue is taken away for analysis in pathology lab. Commonly, this procedure is applied by manually insertion device via X-ray imaging for better control of sampling of focused organ tissue. Instead, human hand controlling biopsy tool, robotic methods can provide higher accuracy and robustness via stiff manipulators which are stable during operation. In addition, biopsy equipped by robotic technique provide trajectory monitoring of needle by imaging approaches such as ultrasound, computed tomography, and magnetic resonance etc.

Currently, biopsy by robot is available for these organs: brain [11], prostate [12], bone [13], breast [14], lung and liver [15and 16]. Moreover, some treatments such thermal ablation is possible by needle device during insertion in suspected tissue [15]. Thus, robotic biopsy is not invasive operation as much as traditional surgery for biopsy.

Firstly, a PUMA robot was utilized for sampling by biopsy needle under compute tomography (CT) vision [17]. In continue of this achievement, a commercial robot for surgery is introduced and named Da Vinci Robotic System. Pore and cones of this robot is reported in terms of accuracy during operations [18 and 19].

The vital point in robotic interventions is generating straight line during penetration biopsy tool and controlling of trajectory is possible by imaging methods. Current work is continuing of the previous efforts of this team in robotics and using AI in mechanical applications [20-25].

This paper is focused on design and fabrication a robot for intervention to take sample by biopsy method. Next, the performance of robot is studied by simulation and lab experiments.

2. Methodology

To establish a robotized biopsy tool, first step is design of proper robot for this purpose. Thus, based on such requirements robot must be designed:

- It must to have minimum vibration trough intervention
- It must provide accessibility in 3D work space for operator to reach suspected organ
- The controller must be robust and simple for operator

Regards to stated points, 5R parallel robot is selected because it has two joints to the ground, and its accuracy for creating complex trajectories is high. Extra degree of freedom is added to it to provide rotation around horizontal axis. Initially, forward and inverse kinematic of robot are mentioned in continue. Next, simulation result and lab experiments for assessment of robot are described.

2.1 Forward and Inverse Kinematic

First, 5R parallel robot which is shown in Fig.1 is considered. It includes links (l_1 , l_2) and active joints (A_1 , A_2). Also, passive joints (P_1 ، P_2) and $E(x.y)$ are considered in Oxy coordinate system.

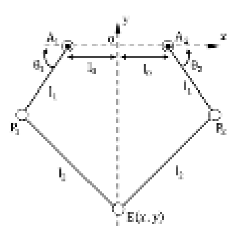

Fig.1 configuration of 5R robot

$P_1$and P_2 can be presented in direct kinematic by:

$P_1(-l_0 - l_1\cos\theta_1 . l_1\sin\theta_1)$

$P_2(l_0 + l_1\cos\theta_2 . l_1\sin\theta_2)$

And created circle by collision of them will be:

$$(x-(-l_0-l_1\cos\theta_1)^2)^2+(y-l_1\sin\theta_1)^2 = {l_2}^2 \quad (1)$$

$$(x-(l_0+l_1\cos\theta_2)^2)^2+(y-l_1\sin\theta_2)^2={l_2}^2 \quad (2)$$

By extending Equation 1, and definition parameters such as α_1, β_1 , γ_1 as following:

$\alpha_1 = 2xl_1 - 2l_0l_1$

$\beta_1 = -2yl_1$

$\gamma_1 = -2xl_0 + {l_2}^2 - {l_1}^2 - y^2 - x^2 - {l_0}^2$

θ_1 can be obtain as bellow:

$$\theta_1 = \cos^{-1}\left(\frac{\gamma_1}{\sqrt{{\alpha_1}^2+{\beta_1}^2}}\right)+\tan^{-1}\left(\frac{\beta_1}{\alpha_1}\right) \quad (3)$$

Next, by extending equation 2 and definition parameters such as α_2 , β_2 , γ_3 as following:

$\alpha_2 = -2xl_2 + 2l_0l_2$

$\beta_2 = -2yl_2$

$$\gamma_2 = +2xl_0 + {l_2}^2 - {l_0}^2 - y^2 - x^2 - {l_2}^2 = \alpha_2\cos\theta_2 + \beta_2\sin\theta_2$$

θ_2 will be known as:

$$\theta_2 = \cos^{-1}\left(\frac{\gamma_2}{\sqrt{{\alpha_2}^2+{\beta_2}^2}}\right)+\tan^{-1}\left(\frac{\beta_2}{\alpha_2}\right)$$

Thus, inverse kinematic is available for make relation between input angles and end effector (E). These equations are necessary in simulation of robot especially in controller design [4-6].

2.2 Design PID Controller

After deriving inverse kinematic of 5R robot, mechanism was modelled in Solid Works Software with 0.0844m, 0.1m, and 0.2m for l_0 , l_1, l_2, respectively. Next, coupling between SolidWorks Software and MATLAB was applied. Fig.2 illustrates simulated 5R Robot. X and Y were input as end-effector trajectory to produce circle in E point. Gains of PID reached by MATLAB as K_p=1 and K_i=1, so PI controller is proper for this purpose based on Equation 4.

$$P + \frac{1}{S} + D\frac{N}{1+N\frac{1}{S}} \quad (4)$$

Fig.2 5R robot modelled by Solid Works Software

3. Results and Discussion

The end effector trajectory was obtained as Fig.3. as can be seen, in first part of output trajectory, there is some instability, but quickly error was rejected by PI controller. In addition, variation of angle of active joints are unveiled in Fig.4 and 5.

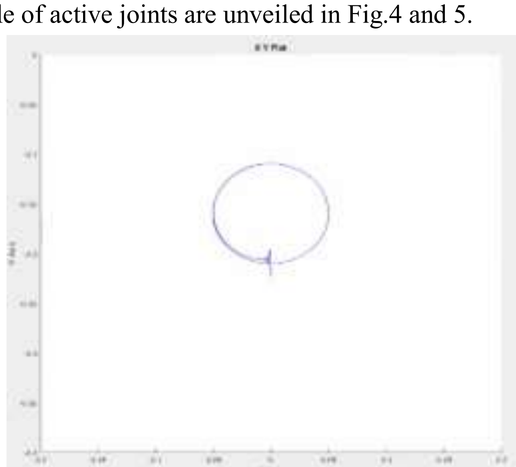

Fig.3 trajectory of end effector

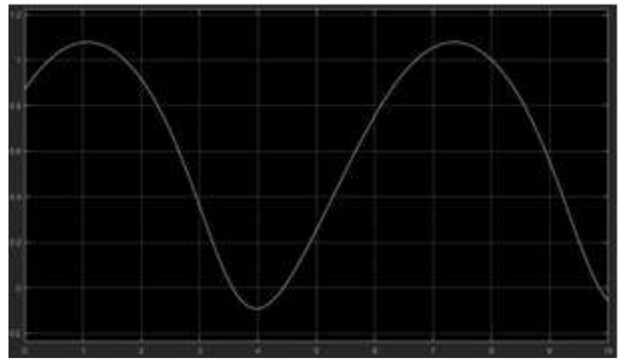

Fig.4 variations of θ_1

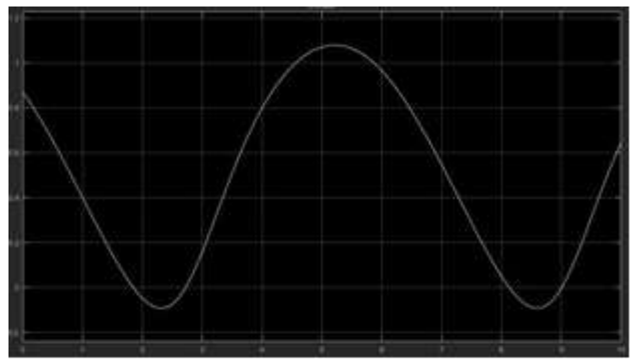

Fig.5 variations of θ_2

Having variations of active joints help us to selecting servomotors in next step. Also, optimization of geometry is related to them [9,10]. In future work, we try to fabricate this robot for medicine injection in biomechanics application.

By reaching to PID controller parameters, a DAQ (Arduino) was programmed and used for controlling 5R robot. This robot is shown in Fig.6. The accuracy of robot in trajectory is studied, and error is around 5%.

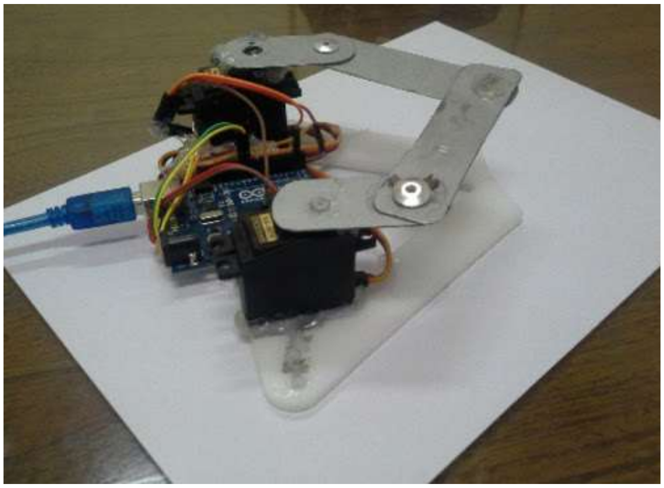

Fig.6 5R robot which was fabricated

4. Conclusion

In this paper configuration of 5R parallel robot were studied by kinematic and dynamic analysis. The Results of simulation and fabricated robot evaluation show that the accuracy of controller is acceptable in terms of trajectory control for the proposed path. The kinematic model which was developed used in controller design could present behavior of motion perfectly. Also, the error of position controller was in standard margin. In future work, it aims to use it for biopsy operation for medical purposes.

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