Estimation of Positional Error in Five-bar Manipulator under the Influence of Tolerances

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Abstract

This paper presents the analysis of positional error in a five-bar planar manipulator operated with variable link tolerances. As part of this research, a new method is developed to analyze the effect of tolerances on the positioning of the end-effector. The results obtained in the proposed method are validated by comparing with graphical method and CAD Model Simulation. Forward and inverse kinematics of the five-bar manipulator in the first quadrant is analyzed for ten different positions. With the permutations and combinations of tolerances on the positioning errors are studied and the maximum error is sought. An effort is made to compensate it. Finally, the effect of transmission angle on the positioning error of the end effector is also studied.

1. Introduction

There are many applications of five bar mechanisms starting from simple machine linkages to complex biomedical equipment. It is widely used in assembly and industrial robotics for material handling applications. The configuration is mostly used as planar manipulator.Manycomplex manipulators can be studied with five link chain as primitive configuration. Performance of the mechanism is most important for any given task. The performance is generally measured in terms of deviation from intended position and orientation of rigid body being guided [1-3]. Synthesis of the planar five bar manipulator is carried out for path generation by the end effector.

2. Methodology

- Forward and inverse kinematic formulations is carried out for the five-bar manipulator by geometrical approach.
- The obtained results are verified with graphical approach and CAD Model simulation done in ADAMS.
- Seven different values of link tolerances in the range from 0.001 to 0.1 are considered for error analysis. Each of the 243 possible combinations of tolerances, 10 end effector positions are analyzed for the maximum positional error.
- Using the IK of the manipulator an effort is made to compensate the maximum positional error of the end-effector.

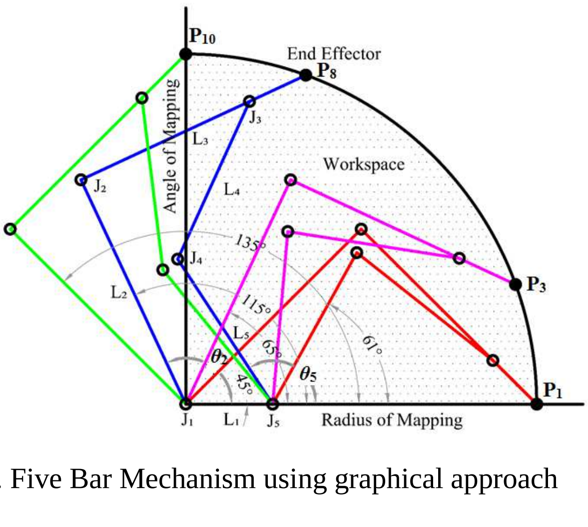

Fig 1. Five Bar Mechanism using graphical approach

3. Positional Error Estimation

3.1 Forward Kinematics

In forward kinematics (Fig. 2), for the known joint angles i.e. θ_1 and $\theta_4$at A and E respectively, the position of the end effector at C is determined as

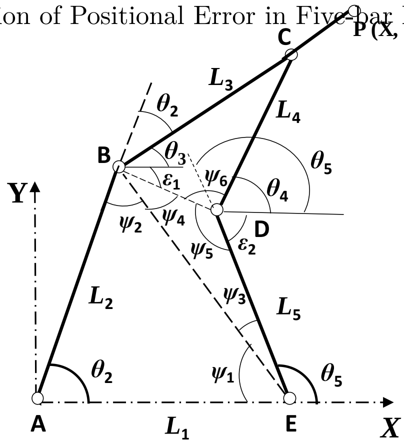

Fig 2. Five Bar Mechanism

$$X_P = L_2 C\theta_1 + L_3 C\theta_2 = L_4 C\theta_3 + L_5 C\theta_4 + L_1 C\theta_0 \quad (1)$$

$$Y_P = L_2 S\theta_1 + L_3 S\theta_2 = L_4 S\theta_3 + L_5 S\theta_4 + L_1 S\theta_0 \quad (2)$$

3.2 Inverse Kinematics

In this method position of the end effector P in the Cartesian coordinate system is given in terms of X and Y, from which the input angles θ_1 and θ_4 is determined. From the below equations (3) & (4), it is observed that, there are always four possible solutions.

$$\cos\lambda_3 = \frac{L_{OE}^2 + L_{EC}^2 - L_{OC}^2}{2L_{OE}L_{EC}} = \frac{(L_1 - X_P)^2 + L_{EC}^2 - Y_P^2}{2(L_1 - X_P)L_{EC}} \quad (3) \qquad \cos\lambda_4 = \frac{L_5^2 + L_{EC}^2 - L_4^2}{2L_5 L_{EC}} \quad (4)$$

4. Results

In the below Fig. 3 and 4, the maximum positional error is at first position (P1) and tolerance at 0.1. As the position changes from initial to final the positional error is observed decreasing. Error is observed maximum at first position as it is close to the toggle position.

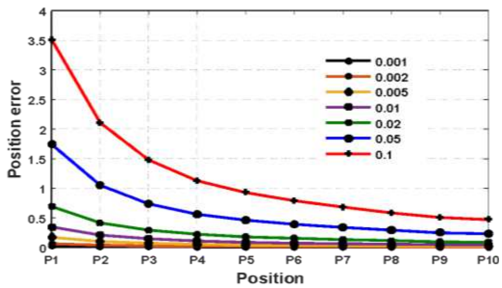

Fig 3. End effector position vs Position error

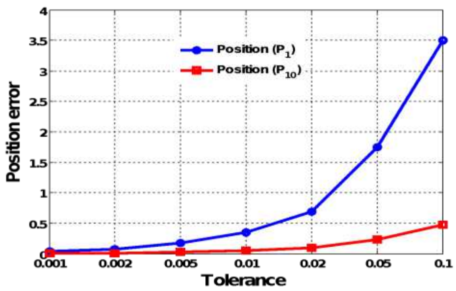

Fig. 4. Link tolerance vs Position Error

In Fig. 4, it can notice that as tolerances increasing the positional error is also increasing. Upto 0.01 tolerance the positional error is less, however the positional errors increased later from 0.01 to 0.1.

5. Summary

A study is conducted on five-bar manipulator by geometrical approach forthe positional errors in the end effector for various tolerance values. Maximum error in each position of the functions are taken.It is observed that when the link tolerance is high, the error is also high, i.e., the positional error is proportional to link-tolerance.At 0.01 tolerance, a drastic shift is observed in the desired accuracy points. The amount of error is also very large.It is observed that the tolerances are out of the acceptable ranges, the non-linearity of the error curve is higher which is not recommended for precision applications like medical instruments.

References

[1] R. Hartenberg, J. Danavit, Kinematic synthesis of linkages, New York: McGraw-Hill, 1964.
[2] R.L. Norton, Design of machinery: an introduction to the synthesis and analysis of mechanisms and machines, Boston: McGraw-Hill Higher Education, 2004.
[3] H. Jawale, H. Thorat, Positional error estimation in serial link manipulator under joint clearances and backlash, Journal of Mechanisms and Robotics, 5 (2013) 021003.