IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Forward and Inverse Kinematics for a Novel Double Scara Robot

IOP Conf. Series: Earth and Environmental Science **170** (2018) 042088 doi:10.1088/1755-1315/170/4/042088

Forward and Inverse Kinematics for a Novel Double Scara Robot

Haoyu Shen[1, a], Yanli Liu[2, b], Hongtao Wu[2, c], Chunlong Hu[1, d] and Shuai Wang[1, e]

[1]College of Mechanical and Electrical Engineering, Shaanxi Institute of Technology, Xi' an 710300, China

[2]College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

[a]shenhaoyu09@163.com, [b]mee_liuyanli@126.com, [c]mehtwu@126.com, [d]1246506073@qq.com, [e]350651776@qq.com

Abstract. This paper presents a novel double scara robot which used in industrial automation for assembling and sorting small components. It has 3 degrees of freedom: translational motion along two orthogonal axes (x, y) and rotational motion around the z-axis. In particular, the design process and development of the novel double scara robot is presented. Then, this paper develops both forward and inverse kinematics models for the novel double scara robot. The correctness and effectiveness of the kinematic solutions was shown by the simulation of the double scara robot. The simulation results for computation of inverse kinematics and forward kinematics of the robot are presented at the end of the thesis. For the choice of the links' dimensions, the calculated solutions from the forward kinematic problem are completely identical to the desired trajectories.

1. Introduction

Robots with various shapes and types are now on its way of diverging into various fields, due to their wide range of application. Among them, parallel robots are generally faster, stronger and more accurate than their serial counterparts of similar size. These mechanisms attract more attention from researchers.

Studies on parallel robot had been launched and researched decades ago. They were originally used to spray paint cars and detect tire. In 1965, a six-DOF parallel mechanism can also be used for flight simulators was first presented in a paper by Stewart. Since Hunt defines Stewart platform mechanism as a robotic system in 1978, the parallel robot technology has been widely promoted. Parallel mechanisms are complementary to serial mechanisms in performance. It compromised a more rigid structure with many obvious advantages over serial robot. Parallel robots own high stiffness, low inertia and relatively large payload capacity. However, Because of complex mechanism, it also has some drawbacks, such as limited workspace and nonlinear dynamics leading to control hardships [1-3].

In parallel robot structures, five bar planar manipulator has a simple structure and its kinematic analysis is relative explicit. However, it has characteristics of high-speed, high-accuracy, low-inertia and high-stiffness [4-8]. In several special industrial processes, while some devices (for example microelectromechanical systems), require no or little assembly other miniaturized products can be composed by several parts that have to be manipulated and assembled. In general, Conventional serial robot used for micro assembly has a large workspace with respect to their size, but repeatability is very low. The use of five bar planar manipulator seems to be promising for their characteristics such as simple control, high stiffness, and high precision [9-11]. For these reasons, research and development of five bar planar manipulator have attracted the attention of a lot of researchers. For example, 'double SCARA' RP-AH series developed by Mitsbishi Electrics, has already been commercialized. DexTAR (Dexterous Twin-Arm Robot), five bar planar manipulator designed by ETS, is to pick and place steel balls [12-13]. With the development of technology, it has the potential to be widely used in industrial automation for assembling and sorting tasks.

For this reason, we design and develop a novel double scara robot (five-bar) for assembling the micro parts. The inverse and forward kinematic analyses of the robot are worked out in detail. In order to verify the kinematics algorithm, the simulation results for computation of inverse kinematics and forward kinematics of the manipulator are presented at the end of the thesis.

2. The structure of double scara robot

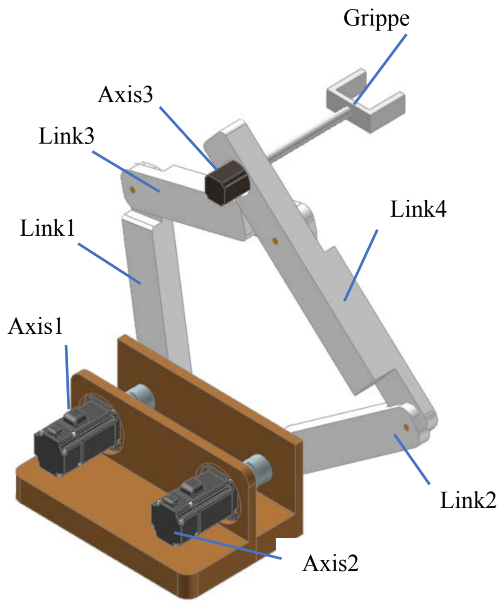

Fig 1. CAD model of the anthropomorphic arm

The structure of double scara robot considered here is shown in Figure 1. The manipulator has 3 degrees of freedom. It can realize translational motion along two orthogonal axes (x, y) for the positioning of micro-parts and a rotational motion around the z-axis for their orientation. And more specifically, the translational motion in the xy-plane is obtained by five bar parallel structure. Finally, the end-effector (gripper) absolute rotation is realized by axis 3. A servomotor, mounted on the link 4, makes axis 3 rotation.

3. Forward Kinematics Model

In this section, the forward kinematic model of the double scara robot is summarized. In the forward kinematic problem, it is assumed that the joint variables are given and the problem is to find the position and orientation of the end-effector. The forward kinematics of parallel robots are usually more complex than the inverse kinematics. For the double scara robot, because of the simplicity of its structure, the forward kinematic solutions can be easily expressed in analytic form.

As shown in Figure 1, O_i denotes the fixed base points of the links, L_i denotes the links' lengths, and q_i denotes revolute angle for joints. The pose of the end-effector is denoted by G = [X_D, Y_D, α] while the variables of the joints are [q_1, q_2, q_3]. In the forward kinematic problem, the joint variable q_i are given, and the position and orientation of the end-effector G = [X_D, Y_D, α] are to be found.

Referring to Figure 2, the following formulas are derived:

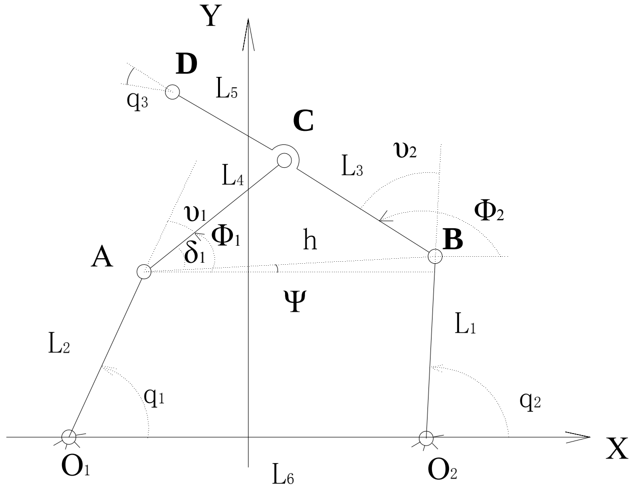

Fig 2. A Schematic for the double scara robot used for forward kinematic analysis of the robot

$$\begin{cases} x_D = x_A + L_4 \cos\Phi_1 + L_5 \cos\Phi_2 \\ y_D = y_A + L_4 \sin\Phi_1 + L_5 \sin\Phi_2 \end{cases}$$

$$\begin{cases} \Phi_1 = \delta_1 + \Psi \\ \Psi = \arctan2(y_B\text{-}y_A, x_B\text{-}x_A) \end{cases} \tag{1}$$

The position of joints A and B can be expressed in a function of joints variables q_i:

$$\begin{cases} x_A = L_2 \cos q_1 - \dfrac{L_6}{2} \\ y_A = L_2 \sin q_1 \end{cases} \quad \text{and} \quad \begin{cases} x_B = L_1 \cos q_2 + \dfrac{L_6}{2} \\ y_B = L_1 \sin q_2 \end{cases} \tag{2}$$

The variables δ_1 can be given by

$$\delta_1 = \pm\arccos(\frac{h}{2L_4}) \tag{3}$$

In which

$$h = \sqrt{(y_B\text{-}y_A)^2 + (x_B\text{-}x_A)^2} \tag{4}$$

The sign $\pm$ in equation 3 depends on the assembly mode of the robot, in this case two solutions can be generated. Finally, the absolute rotation α of the end-effector can be determined as follows:

$$\alpha = \Phi_2 + q_3 \tag{5}$$

Where

$$\Phi_2 = \pi - (\Phi_1 - 2\psi) \tag{6}$$

4. Inverse Kinematics Model

For inverse kinematic analysis, it is assumed that the position and orientation of end-effector (G = [X_D, Y_D, α]) is given and the problem is to find the joint variables of the robot ([q_1, q_2, q_3]). From the relatively simple geometry of the manipulator, the inverse kinematic problem can be easily solved. Referring to Figure 3, the following formulas are derived:

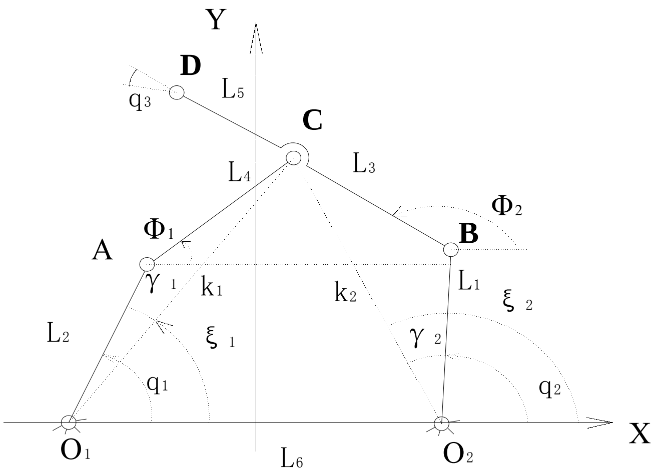

Fig 3. A Schematic for the double scara robot used for inverse kinematic analysis of the robot

$$\begin{cases} q_1 = \xi_1 + \gamma_1 \\ q_2 = \xi_2 - \gamma_2 \end{cases} \tag{7}$$

The two intermediate variables ξ_1, ξ_2, γ_1 and γ_2 are defined as follows:

$$\begin{cases} \xi_1 = \arctan2(y_C, x_C + \dfrac{L_6}{2}) \\ \xi_2 = \arctan2(y_C, x_C - \dfrac{L_6}{2}) \end{cases}$$

In which

$$\begin{cases} x_C = x_D - L_5 \cos \Phi_2 \\ y_C = y_D - L_5 \sin \Phi_2 \end{cases} \tag{8}$$

$$\begin{cases} \gamma_1 = \pm \arccos\left(\dfrac{L_2^{\ 2} + k_1^{\ 2} - L_4^{\ 2}}{2L_2k_1}\right) \\ \gamma_2 = \pm \arccos\left(\dfrac{L_1^{\ 2} + k_2^{\ 2} - L_3^{\ 2}}{2L_1k_2}\right) \end{cases}$$

In which

$$\begin{cases} k_1 = \sqrt{\left(x_C + \dfrac{L_6}{2}\right)^2 + y_C^{\ 2}} \\ k_2 = \sqrt{\left(x_C - \dfrac{L_6}{2}\right)^2 + y_C^{\ 2}} \end{cases} \tag{9}$$

According to the sign chosen for γ1 and γ2, we can obtain four different inverse kinematic solutions of the double scara robot.

Furthermore, the joint coordinates *q*3 can be written as:

$$q_3 = \alpha - \Phi_2 \tag{10}$$

In which

$$\Phi_2 = \pi - (\Phi_1 - 2\psi) \tag{11}$$

5. Simulations

In this section, a simulation study is given to demonstrate the result of the forward kinematic and inverse kinematic solutions in the prevision section. The link length of the double scara robot used in the simulations is chosen as L1=L2 = L3 = L4 = L5= L6 = 1m. As seen in figure 4 and figure 5, 0.5 m motion in the x direction is considered, while a 90◦ rotation is considered for the orientation of the end-effector *α*, in 5 s. For the given trajectory, inverse kinematic solution of the manipulator is obtained and the manipulator the joint variables are uniquely determined and have been illustrated in Figure 6.

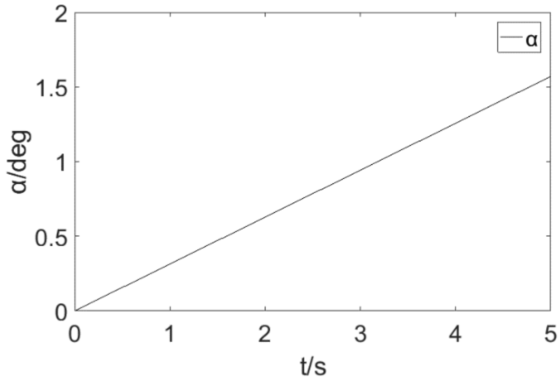

Fig 4. The changes of the attitude of the end-effector

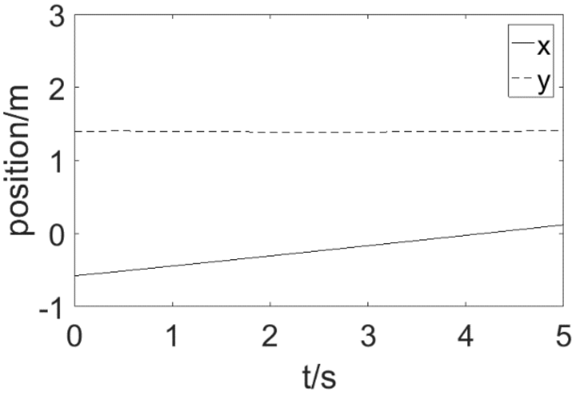

Fig 5. The changes of the position of the end-effector

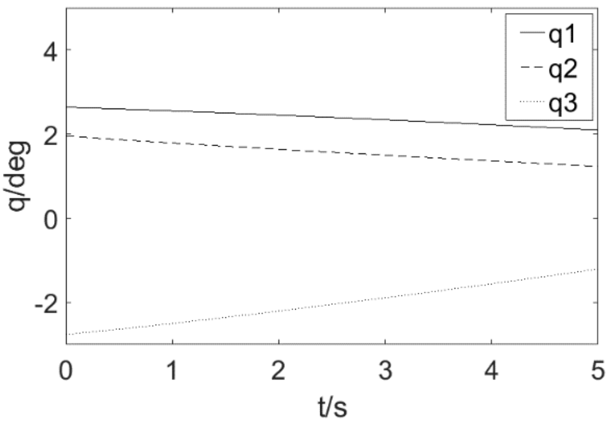

Fig 6. Angles of all joints

As shown in Figure 7, to verify the correctness and effectiveness of the inverse kinematic solutions, the forward kinematic solutions for the manipulator are derived for the given joint variables. The simulation results of robot are shown in Fig. 8. Consequently, the calculated solutions from the forward kinematic problem are completely identical to the desired trajectories. This confirms the correctness and effectiveness of the method to obtain the forward kinematic solution.

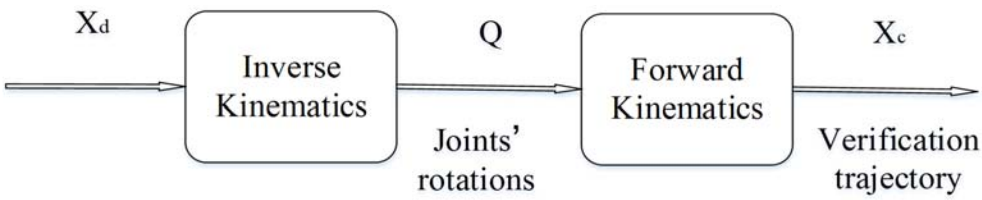

Fig 7. Mechanism of the forward kinematics verification for a given trajectory

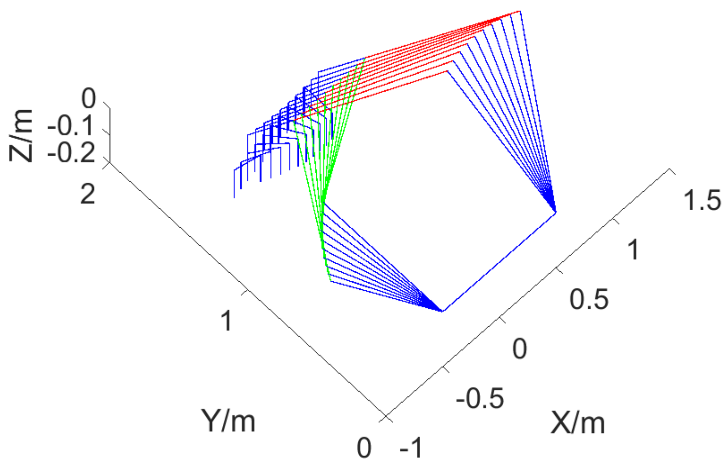

Fig 8. Trajectory of robot

6. Conclusion

In this paper, a new double scara robot for assembly and manipulation of extremely small components for high speed operations was presented. Like the five bar parallel structure, this robot has simple architecture, accurate repeatability and high stiffness. It has 3 degrees of freedom: translational motion along two orthogonal axes (x, y) and rotational motion around the z-axis.

Its forward kinematic and inverse kinematic models were developed. The correctness and effectiveness of the kinematic solutions was shown by the simulation of the double scara robot. For the choice of the links' dimensions, the calculated solutions from the forward kinematic problem are completely identical to the desired trajectories.

Acknowledgments

This work is supported by the National Natural Science Foundation (Grant No. 51375230), the University's Natural Science Research Project of Jiangsu Province (No. 17KJB460003) and the Foundation of Shaanxi Institute of Technology (Grant No. Gfy17－25).

References

[1] Dong H W, Li P K. The Current Situation and Development of Parallel Robot in China [J]. Automation Panorama, 2005, 22(4): 86-88.
[2] Qiu Z Tan D L, Zhao M Y. Current Situation of Research on Parallel Robots [J]. Machinery, 38 (428): 27-29.
[3] Chen X. Recent Development and Current Status of Stewart Platform Research [J]. Robot, 2002, 24(5): 464-470.
[4] Joubair A, Slamani M, Bonev I A. Kinematic calibration of a five-bar planar parallel robot using all working modes [J]. Robotics and Computer-Integrated Manufacturing, 2013, 29(4):15-25.
[5] Zi B, Cao J, Zhu Z. Dynamic Simulation of Hybrid-driven Planar Five-bar Parallel Mechanism Based on SimMechanics and Tracking Control [J]. International Journal of Advanced Robotic Systems, 2011, 8(4): 28-33.
[6] Joubair A, Bonev I A. Comparison of the efficiency of five observability indices for robot calibration [J]. Mechanism & Machine Theory, 2013, 70(6):254-265.
[7] Takeda Y, Shen G, Funabashi H. A DBB-Based Kinematic Calibration Method for InParallel Actuated Mechanisms Using a Fourier Series [J]. Journal of Mechanical Design, 2004, 126 (5): 1201-1210.

IOP Conf. Series: Earth and Environmental Science **170** (2018) 042088 doi:10.1088/1755-1315/170/4/042088

[8] Alici G, rsel. An inverse position analysis of five-bar planar parallel manipulators [J]. Robotica, 2002, 20(2): 195-201.
[9] Shariatee M, Akbarzadeh A, Mousavi A, et al. Design of an economical SCARA robot for industrial applications[C]// Second Rsi/ism International Conference on Robotics and Mechatronics. IEEE, 2014: 534-539.
[10] Germain C, Briot S, Glazunov V, et al. IRSBot-2: A Novel Two-DOF Parallel Robot for High-Speed Operations [C]// ASME 2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. 2011: 899-909.
[11] Hesselbach J, Helm M B, Soetebier S. Connecting Assembly Modes for Workspace Enlargement [M]// Advances in Robot Kinematics. Springer Netherlands, 2002: 347-356.
[12] Joubair A, Slamani M, Bonev I A. Kinematic calibration of a five-bar planar parallel robot using all working modes [J]. Robotics and Computer-Integrated Manufacturing, 2013, 29(4): 15-25.
[13] Campos L, Bourbonnais F, Bonev I A, et al. Development of a Five-Bar Parallel Robot With Large Workspace [C]// ASME 2010 International Design Engineering Technical Conferences. 2010: 917-922.