ECCOMAS Thematic Conference on Multibody Dynamics
July 24- 28, 2023, Lisbon, Portugal

Design of Fixed-Sequence Planar 5R Parallel manipulators with Adjustable Links

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EXTENDED ABSTRACT

1 Introduction

The problem of moving a gripper through a path ensuring only its predetermined initial and final positions is a problem often encountered in various automation tasks. In other words, achieving the objective of moving the gripper along a non-imposed trajectory between two given positions, with the ability to change these positions periodically. One solution to the problem is to create fixed sequence manipulators with adjustable parts. The merit of the solution is that manipulation systems of this type with cyclic control have only one actuator. Note that the cyclic control system improves the operational reliability of the manipulation system and greatly reduces the cost of it. Such an approach has been used in [1]-[4].

The present study proposes a new concept for the design of fixed-sequence planar 5R symmetrical parallel manipulators. The aim of the proposed design principle is that the two input links of the manipulator are interconnected. This interconnection is carried out via a four-bar linkage with adjustable links. The link lengths are determined in such a way that the initial and final positions of the gripper are ensured. Numerical simulations are performed to illustrate the proposed design concept.

2 Statement of the problem

Figure 1 illustrates a kinematic scheme of the planar 5R parallel manipulator. The output axis $P(x,y)$, which corresponds to the axis of the gripper, is connected to the base by two legs, each of which consists of three revolute joints and two links. The two legs are connected to a common axis P with the common revolute joint at the end of each leg. In each of the two legs, the revolute joint connected to the base is actuated. Such a manipulator can position the gripper freely in the plane xOy.

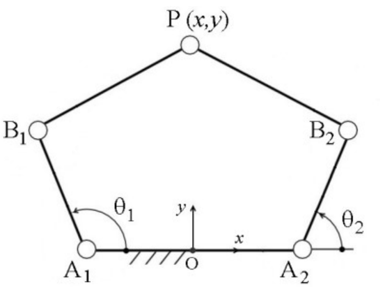


Figure 1: Planar 5R parallel manipulator.

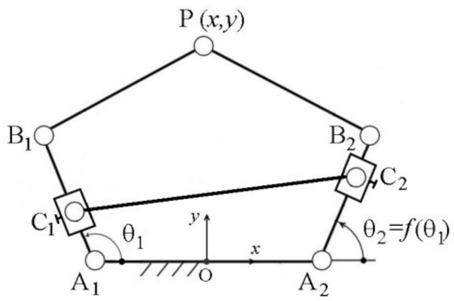


Figure 2: Fixed-sequence planar 5R parallel manipulator.

Now, let us consider that it would be necessary to handle a payload ensuring only two prescribed positions: initial and final. That is, the payload's path of motion is not imposed and may be an arbitrary curve. This is often the case with many tasks of picking up the payload and placing it in another location. Such a task can also be repetitive within a specified time limit. Certainly, it can be achieved via a planar 5R manipulator with two degrees of freedom. However, given the conditions described, it is more reasonable to transform the 5R parallel manipulator into a mechanical system with one degree of freedom. For this purpose, an adjustable transmission system will be added to modify the initial structure of the manipulator (Figure 2). The added link C_1C_2 will form a four-bar mechanism providing the required rotation angles θ_1 and θ_2 for input links. The suggested methodology is considered optimal in terms of its simplified control and minimum energy expenditure.

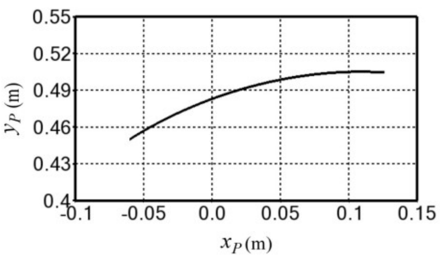
3 Synthesis of fixed-sequence manipulators with adjustable links

Thus, if the initial x_i, y_i and the final x_f, y_f positions of output axis $P(x,y)$ are known, the initial and final values θ_{1i}, θ_{1f} and θ_{2i}, θ_{2f} of the angles θ_1 and θ_2 can be obtained from the inverse kinematics [5]. The synthesis of the linkage $A_1C_1C_2A_2$ can be achieved by determining the lengths of the links A_1C_1 and A_2C_2: $l_{A_1C_1} = L_2$ and $l_{A_2C_2} = L_4$, taking into account that the non-dimensional lengths of the links C_1C_2 and A_1A_2: $l_{C_1C_2} = L_3$ and $l_{A_1A_2} = L_1 = 1$ are known. By formulating the conditions of the geometric synthesis of the linkage $A_1C_1C_2A_2$, the unknown length $l_{A_1C_1} = L_2$ can be obtained from the polynomial equation:

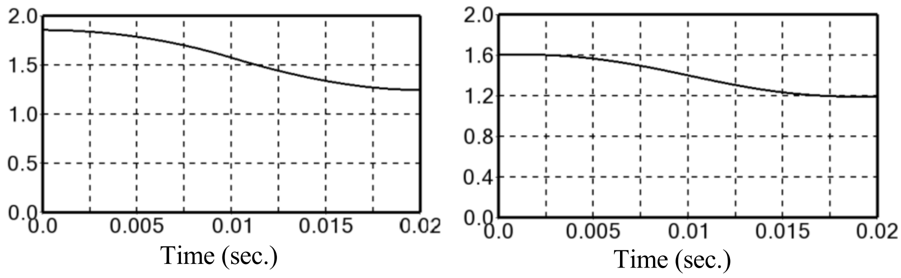
$a_4L_2^4+a_3L_2^3+a_2L_2^2+a_1L_2+a_0=0$, with $a_4=\beta_3^2$; $a_3=2\left(\beta_2\beta_3-\alpha_3\beta_1\beta_3-\alpha_1\beta_3^2\right)$; $a_2=-\beta_3^2L_3^2+\beta_1^2+\beta_2^2-2\alpha_3\beta_1\beta_2+2\alpha_2\beta_1\beta_3-4\alpha_1\beta_2\beta_3+\beta_3^2$; $a_1=-2\left(\beta_2\beta_3L_3^2+\alpha_2\beta_1\beta_2-\alpha_1\beta_2^2+\beta_2\beta_3\right)$; $\alpha_0=\beta_2^2\left(1-L_3^2\right)$, where, $\alpha_1=\cos\theta_{1i}$; $\alpha_2=\cos\theta_{2i}$; $\alpha_3=\cos\left(\theta_{2i}-\theta_{1i}\right)$; $\beta_1=\cos\theta_{1i}-\cos\theta_{1f}$; $\beta_2=\cos\theta_{2i}-\cos\theta_{2f}$; $\beta_3=\cos\left(\theta_{2f}-\theta_{1f}\right)-\cos\left(\theta_{2i}-\theta_{1i}\right)$. Then, the unknown length $l_{A_2C_2}=L_4$ will be determined: $L_4=\beta_1L_2/\left(\beta_2+\beta_3L_2\right)$.

4 Illustrative example and simulation results

To illustrate the suggested design concept, the following geometric parameters of the planar 5R manipulator have been used: $l_{A_1B_1}=l_{A_2B_2}=0.36\text{m}$; $l_{B_1P}=l_{B_2P}=0.3\text{m}$; $l_{OA_1}=l_{OA_2}=0.24\text{m}$. The trajectory of the gripper P is given by the initial position P_i with the coordinates $x_i=-0.06\text{m}$, $y_i=0.45\text{m}$ and the final position P_f with the coordinates $x_f=0.126\text{m}$, $y_f=0.504\text{m}$. From these values, the initial and final positions of the angles θ_1 and θ_2 are calculated: $\theta_{1i}=1.856$ rad., $\theta_{1f}=1.246$ rad., $\theta_{2i}=1.609$ rad., $\theta_{2f}=1.191$ rad. For the given values $l_{A_1A_2}=L_1=1$ $(l_1=0.48\text{m})$ and $l_{C_1C_2}=L_3=1.05$ $(l_3=0.504\text{m})$, the following polynomial equation was obtained: $0.000818847L_2^4+0.010354434L_2^3+0.039319218L_2^2+0.077263101L_2-0.017110121=0$. From which the length of the link A_1C_1 is determined: $L_2=0.2$ $(l_2=0.096\text{m})$ and then from $L_4=\beta_1L_2/\left(\beta_2+\beta_3L_2\right)$, the length of the link A_2C_2: $L_4=0.298$ $(l_4=0.143\text{m})$.



Figur 3. Trajectory of the gripper.



Figur 4. Variations of the angle θ_1 and he angle θ_2 (rad). (rad).

To validate the numerical example, simulations have been carried out on the software ADAMS. By these simulations, it was approved that the developed manipulator ensures the given initial and final positions of the gripper. The trajectory of the gripper, the variations of the angles θ_1 and θ_2 are shown in figures 3 and 4. It is obvious that when changing the initial and final positions of the gripper, the lengths of the links A_1C_1 and A_2C_2 must be adjusted.

4 Discussion

The author believes that the proposed solution is practical, feasible and cost-effective, and applications for it can be found in areas requiring fast manipulation. The examined problem can also be solved for three given positions of the gripper, i.e. adding an intermediate position between the initial x_i, y_i and the final x_f, y_f positions. In this case, the length of the link C_1C_2 will also be adjustable. However, it should be noted that the mathematical solution in this case will be much easier, since it is necessary to solve a system of linear equations and to find the parameters $l_{A_1C_1}=L_2$, $l_{C_1C_2}=L_3$ and $l_{A_2C_2}=L_4$.

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