Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(Special Issue 4) (2021) 569-572
DOI: 10.22060/mej.2020.17378.6585

Torque minimization of 2-DOF parallel robot using counterweights and trajectory planning

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ABSTRACT: This paper investigates the point-to-point motion of the end effector of a 2-DOF parallel robot with minimum torque consumption. The presented method improves the dynamic performance of the robot. This method compensates the inertia force, gravity, Coriolis and the centrifugal terms of the system. The design parameters and optimal trajectory of the robot are simultaneously obtained for a predefined point-to-point motion. Two adjustable counterweights are attached to each active link. The mass of the counterweights and the installation angle of them are considered as design parameters. The optimal trajectory of the robot is obtained by the third-order spline interpolation. Minimum-effort is the objective function of the problem. The numbers cup optimization method is used to find optimum values of the design variables of trajectory and design parameters of the robot. The simulation results show that the objective function has been approximately reached zero value. An experimental robot was developed to verify the simulation results and illustrate the efficiency of the proposed approach. With adjusting the design parameters of the robot, the servo-actuators are operated in position control mode. The experimental outputs show that the objective function has been reduced by about 90% compared to the typical form of the robot.

Review History:

Received: Dec. 13, 2019
Revised: Mar. 16, 2020
Accepted: May, 03, 2020
Available Online: May, 23, 2020

Keywords:

Torque minimization
2-DOF parallel robot
Counterweights
Optimal trajectory
Optimization

1- Introduction

In many practical situations, the end effector needs to a planar motion for a point-to-point task. For this particular problem, the planar 2-DOF parallel robot is introduced. Huang et al. proposed an approach for the optimal design of a planar 2-DOF parallel robot [1]. Dincer and Cevik introduced a new composite polynomial for the trajectory planning of a 2-DOF parallel mechanism [2].

Torque minimization of the robotic systems is a significant problem in the point-to-point motions. A review of related literature shows that the minimization problem can be classified into two groups. In the first group, mass or geometric parameters of the robot aren't considered as design parameters [3, 4]. In the second group, robot parameters are introduced as the design variables determined by solving the problem [5-7].

In this paper, a new approach is presented for torque minimization of the 2-DOF parallel robot. For a predefined point-to-point task, the proposed method is formulated as an optimization problem. To considerable reduction of the applied torques, the design parameters of the robot and the optimal trajectory are calculated simultaneously. The mass of the counterweights and the installation angle of them, with reference to the robot links, are considered as design parameters.

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2- Dynamic Modeling of 2-DOF Parallel Robot

The dynamic model for a 2-DOF parallel robot is derived considering the counterweights. A kinematic scheme of the robot is shown in Fig. 1.

Using the Lagrange-Euler formulation, the final dynamic equation of the robot is obtained as follows:

$$M\ddot{X}_p + N + G = J^T\tau\,, \tag{1}$$

where M, N and G are the matrices of inertia, Coriolis and centrifugal, and gravity terms, respectively. J is the Jacobian matrix. Also, the vector τ is the applied torque at the active joints A_1 and A_2.

3- Optimizer Algorithm

In the optimizer algorithm, the trajectory of the robot and the design parameters of the counterweights are calculated simultaneously to optimize the objective function for a predefined point-to-point motion. This motion contains forward and returns motions. For the 2-DOF parallel robot, parameters m_{c1}, m_{c2}, α_{c1} and α_{c2} of the counterweights are taken as design parameters. The third-order spline interpolation is used for the trajectory planning of the robot. The middle points of spline interpolation are unknown variables. The objective function of the optimization problem is minimum effort. It is defined as follows:

$$F = \int_0^{t_f} (\tau_1^2 + \tau_2^2)\,dt\,. \tag{2}$$

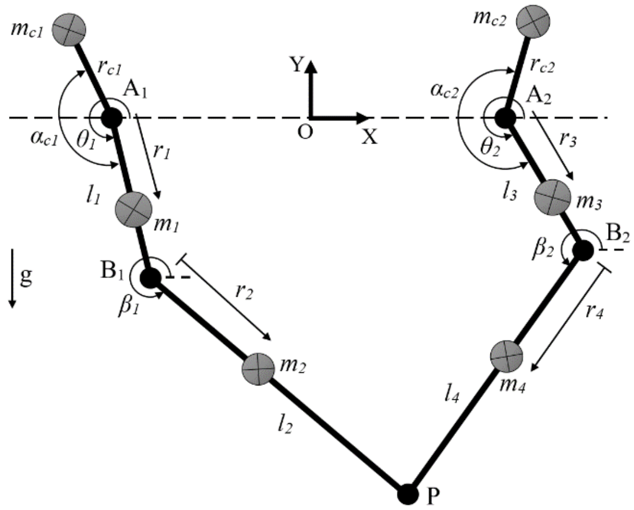


Fig. 1. A kinematic scheme of the 2-DOF parallel robot with counterweights

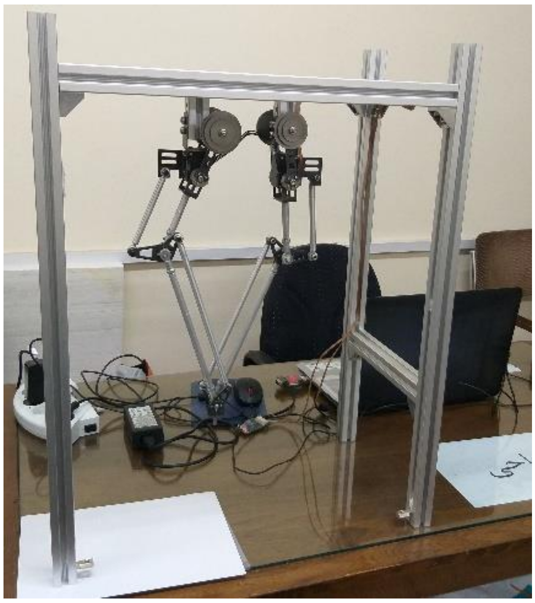


Fig. 2. The 2-DOF parallel robot with two adjustable counterweights

The value of F is placed between zero to positive infinity. Thus, the global optimal value is zero. The numbers cup optimization method is used to obtain the optimal values of design variables [8].

4- Experimental Setup

For experimentation, a 2-DOF parallel robot with adjustable counterweights was designed in Robotics Lab. The robot is shown in Fig. 2.

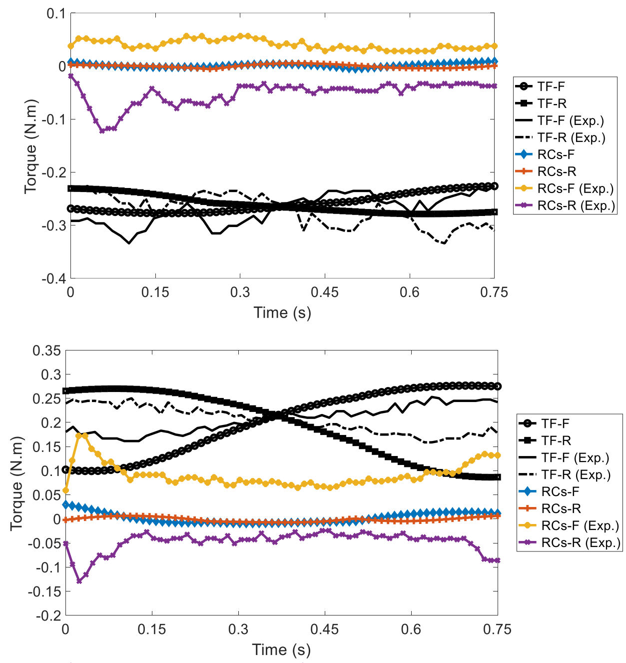
5- Simulation and Experimental Results

To implement the proposed method, two cases are considered: Typical Form (TF) of the robot and Robot with Counterweights (RCs). In the TF case, the 2-DOF parallel robot is considered without counterweights, i.e., $mc_1 = mc_2 = 0$. The following boundary condition is considered for point-to-point motion:

$$x_0 = -0.1,\; y_0 = -0.3,\; x_f = 0.05,\; y_f = -0.25$$
$$\dot{x}_0 = \dot{y}_0 = \dot{x}_f = \dot{y}_f = 0\;;\; t_f = 0.75s \tag{3}$$

For the forward and return motions, the numerically simulated and experimentally observed values of applied torques of the robot are plotted in Fig. 3. As seen in this Figure, the torque at active joints upon implementing the RCs, the obtained values were considerably lower than those with the TF case.

Table 1 presents the values of the objective function under different conditions, according to Eq. (2). As seen in Table 1, the reduction of the objective function in the RCs case is about 100% for theoretical simulation. Also, the reduction of the corresponding value in the experimental implementation is about 90%.



F: Forward, R: Return, Exp.: Experimental

Fig. 3. Applied torque to joints A_1 (up) and A_2 (down)

Table 1. Value of objective function

Condition		F ((N.m)^2.s)
TF	The.	0.0837
	Exp.	0.0882
RCs	The.	0.5809×10^{-4}
	Exp.	0.0062

The.: Theoretical

6- Conclusions

In this paper, a new approach is presented to considerably reduce of the applied torques of the 2-DOF parallel robot. In the simulation results, the global optimal value of the objective function has been achieved by the proposed method. To demonstrate the capability of the method, an experimental setup was manufactured. In the practical implementation, significantly lower objective function values were obtained for the robot on which the RCs were applied, as compared to the typical form of the robot. The presented method can be useful for the high repetitive motion.

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HOW TO CITE THIS ARTICLE

M. Riyahi Vezvari, A. Nikoobin, A. Ghoddosian, Torque minimization of 2-DOF parallel robot using counterweights and trajectory planning, Amirkabir J. Mech. Eng., 53(Special Issue 4) (2021) 569-572.

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