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A NOVEL APPROACH FOR DYNAMIC PARAMETERS ESTIMATION OF A DELTA PARALLEL ROBOT DYNAMIC USING PSO ALGORITHM

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Abstract. In this paper, a novel approach for dynamic parameters estimation problem of delta parallel robot is presented. For the parallel mechanism is highly coupled and nonlinear, an accurate dynamic model is of high importance for the model-based controller's design to obtain satisfactory performance. To develop this estimation, a Solidwork/Matlab/simscape/multibody model was used. Particle swarm optimization (PSO) algorithm is employed for parameters estimation. The simulation results strongly validate the effect of the proposed approach that is employed in the curve fitting of actual torques.

1. Introduction

The term smart factory is much closer to todays industry. The requirement for programmable robots that can quickly move objects from one position to another or track the desired trajectory in 3D spaces through high accuracy becomes more and more every day. For this reason, it is necessary to obtain high precision dynamic robots (parallel robots) to perform tasks[5].
Equations of Euler-Lagrange, Newton-Euler and virtual work principle[1] are the most common methodology to achieve the dynamic model of robots. Due to the force of Coriolis, frictions and etc, obtaining dynamic model parameters is complexed. Estimation of parameters is strong technique to solve the mentioned problem. From[8]-[2], estimation of inertia and unknown friction parameters for serial robots are obtained during trajectories. Especially in parallel robots because of high-coupled dynamics from robot mechanic, the estimation process is complicated. The requirement of joint and spatial position, velocity, acceleration and actual torques are increasing the complicity of the parameters

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estimation process[3]-[6]. This paper presents a novel approach for the parametric estimation of 3-DOF delta parallel robot dynamic model. The necessaries data using Solidworks/Matlab/SimScape/Multibody of delta robot is provided for Euler-Lagrange model. Then, PSO algorithm is perform the process of estimating the dynamic parameters through the path1. Also, path2 is employed to confirm the performance of the dynamic model obtained from the estimated parameters. The root mean square error (RMSE) of actual torques is present of two-path for proposed dynamic validation is presented.
The article rest parts are organized as follows. In Section1.1, first structure and dynamic model of delta robot are described in summary. Then in Section1.2 parametric estimation of delta robot using the PSO algorithm is accomplished. Finally, simulation results and validation of proposed estimation are presented in Section2.

1.1. **DELTA ROBOT.** In 1988, Delta Robot invented by Reymond Clavel [4]. As shown in Fig.1 Delta parallel has three revolute joints on a fixed base and three kinematic chains that connected to the moving plate. For each kinematic chain, a and b described the length of the upper arm and lower arm, respectively. Similarly, r_a and r_b are radius of the fxed plate and moving plate, respectively. $\phi_i(0°, 120°, 240°)$ is angle of each arm respect to coordinate system. θ_i is denoted joint position angle for $i = 1, 2, 3$.

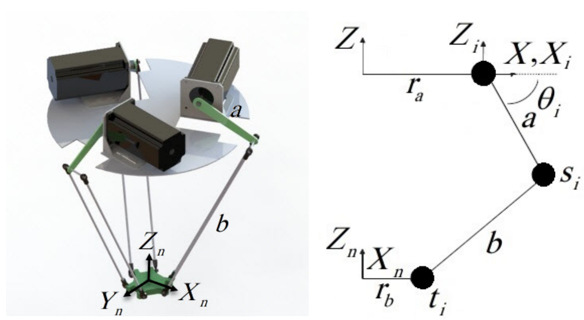

FIGURE 1. Geometrical model of Delta parallel robot.

1.2. **Delta robot parametric estimation using the PSO algorithm.** In this paper, dynamic modeling of delta parallel robot is obtained using the Euler-Lagrangian method. From [7], based on the Euler-Lagrangian method the joint torques are calculated by

$$\tau_i = \left(I_{inr} + \tfrac{1}{3}m_a a^2 + m_b a^2\right)\ddot{\theta}_i + \left(\tfrac{1}{2}m_a + m_b\right) ag\cos\theta_i - 2\lambda_i[(x\cos\phi_i + y\sin\phi_i + r_a - r_b)\sin(\theta_i) - z\cos\theta_i] \quad (1.1)$$

where λ_i is the Lagrangian. τ_i the applied torque to actuator i, m_b and m_b are mass of the upper arm and lower arm mass, respectively. $\ddot{\theta}_i$ is joint acceleration of each arm for $i = 1, 2, 3$. g is the gravity acceleration and I_m denots the delta robot motors inertia. Here, due to the complexity of the robot dynamics, fourteen unknown parameters are assumed as β to reduce complexity. The PSO algorithm is a random search method inspired by the social behavior of the birds. In this paper, this algorithm is used to estimate the dynamical model parameters β_i. To tuning the dynamic unknown parameters with PSO, Eq.(17) is rewritten as a matrix as follows

$$\begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \end{bmatrix} = \begin{bmatrix} \psi_{11} & \psi_{12} & \psi_{13} & \psi_{14} & \psi_{15} & \psi_{16} & \psi_{17} & \psi_{18} & \cdots & \psi_{114} \\ \psi_{21} & \psi_{22} & \psi_{23} & \psi_{24} & \psi_{25} & \psi_{26} & \psi_{27} & \psi_{28} & \cdots & \psi_{214} \\ \psi_{31} & \psi_{32} & \psi_{33} & \psi_{34} & \psi_{35} & \psi_{36} & \psi_{37} & \psi_{38} & \cdots & \psi_{314} \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_{14} \end{bmatrix} \tag{1.2}$$

where

$$\begin{array}{llllll} \beta_1 = I_m + \frac{1}{3}m_a a^2 + m_b a & \beta_4 = 2\lambda_1 & \beta_7 = 2\lambda_2 \cos\phi_2 & \beta_{10} = 2\lambda_2(r_a - r_b) & \beta_{13} = 2\lambda_3 & \\ \beta_2 = 2\lambda_1 \cos\phi_1 & \beta_5 = \left(\frac{1}{2}m_a + m_b\right) ag & \beta_8 = 2\lambda_2 \sin\phi_2 & \beta_{11} = 2\lambda_3 \cos\phi_3 & \beta_{14} = 2\lambda_3(r_a - r_b) & \\ \beta_3 = 2\lambda_1 \sin\phi_1 & \beta_6 = 2\lambda_1(r_a - r_b) & \beta_9 = 2\lambda_2 & \beta_{12} = 2\lambda_3 \sin\phi_3 & & \\ \psi_{11} = \ddot{\alpha}_1 & \psi_{16} = \sin\alpha_1 & \psi_{21} = \ddot{\alpha}_1 & \psi_{210} = \sin\alpha_2 & \psi_{31} = \ddot{\alpha}_3 & \psi_{314} = \sin\alpha_3 \\ \psi_{12} = -x\sin\alpha_1 & \psi_{17} = \psi_{18} = 0 & \psi_{25} = \cos\alpha_2 & \psi_{22} = \psi_{23} = 0 & \psi_{35} = \cos\alpha_3 & \psi_{32} = \psi_{33} = 0 \\ \psi_{13} = -y\sin\alpha_1 & \psi_{19} = \psi_{110} = 0 & \psi_{27} = -x\sin\alpha_2 & \psi_{24} = \psi_{26} = 0 & \psi_{311} = -x\sin\alpha_3 & \psi_{34} = \psi_{36} = 0 \\ \psi_{14} = -z\cos\alpha_1 & \psi_{111} = \psi_{112} = 0 & \psi_{28} = -y\sin\alpha_2 & \psi_{211} = \psi_{212} = 0 & \psi_{312} = -y\sin\alpha_3 & \psi_{37} = \psi_{38} = 0 \\ \psi_{15} = \cos\alpha_1 & \psi_{113} = \psi_{114} = 0 & \psi_{29} = z\sin\alpha_2 & \psi_{213} = \psi_{214} = 0 & \psi_{313} = z\sin\alpha_3 & \psi_{39} = \psi_{310} = 0. \end{array}$$

Trajectory selection is one of the most important tasks in the estimation process because it must ensure that the robot covers almost of its workspace to observe the dynamic behavior of the robotic system. As shown in Fig.2 path1 is used in the estimation process and the path2 is employed to validation of estimated dynamic model.

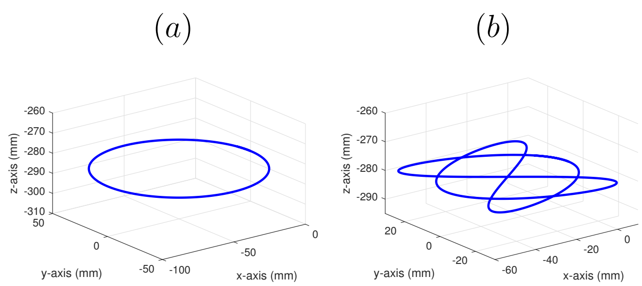

FIGURE 2. Generated trajectories. (a):path1; (b):path2

2. Simulation result

PSO algorithm is accomplished for 10000 iteration with fitness function is defined with MSE errors of torque errors. Obtained parameters is shown in Table.1 and As shown in Fig.3, the behavior of the applied torque of each joint in the proposed estimated dynamic model is so similar to torque of the simscape model. In addition, the specific performance index to quantify the performance of Delta robot dynamic model that is estimated with PSO in trajectory tracking is RMSE of actual joint error. The value of RMSE error of applied torque for both path is presented is Table.2. As can be seen, the estimated parameters for the dynamic model in this paper have high performance in a variety of path. This indicates that the estimated dynamic model of delta robot can be used in the implementation of advanced control technique for trajectory tracking.

TABLE 1. Dynamic model constant parameters

parameter	value	parameter	value	parameter	value	parameter	value	parameter	value
X_1	0.2323	X_4	0.0266	X_7	0.0952	X_{10}	0.3910	X_{13}	0.0507
X_2	0.1377	X_5	0.1572	X_8	-0.1667	X_{11}	0.1066	X_{14}	-0.0586
X_3	-0.5505	X_6	0.2851	X_9	0.0314	X_{12}	0.5018		

TABLE 2. Dynamic model constant parameters

index	$path1$			$path2$		
	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3
$RMSE$	0.0015	$9.4694 * 10^{-4}$	$6.2904 * 10^{-4}$	0.2323	0.0952	0.2323

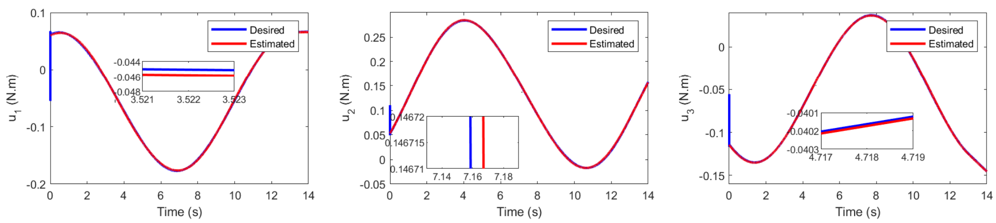

FIGURE 3. Aapplied torques of simscape model and estimated dynamic model for each arm, respectively.

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