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Adaptive robust control for spatial hydraulic parallel industrial robot

Chifu Yang[a]*, Shutao Zheng[a], Xinjie Lan[b], Junwei Han[a]

[a]*Dept. Mechanical and Electrical Engineering, Harbin Institute of Technology, Harbin, 150001, China*
[b]*701 Institute, China Shipbuiding Industry Corporation, Wuhan, 430000, China*

Abstract

This paper proposes an adaptive robust control for spatial hydraulic industrial robot, with a view of improving the performance of trajectory tracking under varying uncertainty. The mathematical models of mechanical system and electro-hydraulic driven system of spatial 6-DOF industrial robot are described, under Kane method and hydromechanics method. The backstepping design methodology is adopted to develop the nonlinear adaptive robust control scheme, which treats the modeling errors and coupling as bounded disturbances, and regards parameters without a priori knowledge as parametric disturbances. The dynamic tracking performances of the closed-loop system with the proposed control for the industrial robot are validated via simulation. The theoretical and simulation results demonstrate that the developed controller can exhibit good tracking performance

Keywords: Industrial robot; adaptive robust control; hydraulic system; trajectory tracking;

1. Introduction

Hydraulic parallel industrial robots are often used in the fields of motion or mechanics environmental simulation, such as high precision space docking motion system, high fidelity flight simulator, vehicle simulator, ship simulator, and load test rigs, by virtue of their advantages of special loading capability,

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* Corresponding author. Tel.: +86-451-86402642-325; fax: +86-451-86412558.
E-mail address: ycf1008@163.com.

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high stiffness, high accuracy, and high force-to-weight ratio and so on [1-2]. On the other hand, such parallel industrial robots have some disadvantages of strong dynamic coupling and high nonlinearity resulted from system complex dynamic characteristics, which may limit the potential development of hydraulic parallel robots. Therefore, high performance controller is necessary and significant for spatial hydraulically driven parallel industrial robot.

In system and control community, spatial parallel robot has attracted special attention to develop effective controller for a typical multi-input multi-output (MIMO) nonlinear system [3]-[4]. The control strategies for robots may be largely divided into two schemes, motion control [5]-[6], and model-based control [7]-[8]. Motion control can be readily implemented as a collection of multiple, independent single-input single-output control system using data on each actuator length only, but it does not always guarantee a high performance for any case. Model-based controllers are developed to improve control performance by taking dynamics characteristics of controlled member into account, such as robust control [9], and adaptive control [10]. The adaptive controllers are presented for industrial robots in [11], yet, the property of driven system is not considered. In [12], the electronically driven systems are considered in control design. Unlike electrically driven robots, hydraulic robots exhibit significant nonlinear actuator dynamics, which is more challenging.

The main contribution of this paper is to propose an adaptive robust controller (ARC) for spatial hydraulic parallel robot with high nonlinearities and uncertainty to get excellent tracking performance. The spatial industrial robot is described as multi-rigid bodies, for which the dynamics is described using Kane method, as well as hydraulic system obtained by applying hydrodynamics. With consideration of the dynamics of the nonlinear driven system and multi-body system, the adaptive robust control, based on backsteping methodology, is designed to improve control performance of hydraulic industrial robot. The system friction is compensated by a LuGre model updated with adaptive control, and the system uncertainties are rejected by a robust control law.

2. Hydraulic Robot Dynamics

The kinematics and dynamics of spatial parallel industrial robot have been investigated extensively [1-2]. Hence, the dynamic equation of mechanical system is briefly described for the parallel industrial robot. The dynamic model of hydraulic robot can be described as

$$\boldsymbol{M}(\boldsymbol{q})\ddot{\bar{\boldsymbol{q}}} + \boldsymbol{C}(\boldsymbol{q},\dot{\bar{\boldsymbol{q}}})\dot{\bar{\boldsymbol{q}}} + \boldsymbol{G}(\boldsymbol{q}) = \boldsymbol{J}_{l\bar{q}}{}^{T}(\boldsymbol{q})\boldsymbol{F}_{L} \tag{1}$$

$$q_{Li} = c_d \cdot w \cdot x_{vi}\sqrt{\frac{1}{\rho}(p_{\mathrm{s}} - \mathrm{sign}(x_{vi})p_{Li})} \tag{2}$$

$$q_{Li} = A_1 \cdot \dot{l}_i + c_{tc}p_{Li} + c_{tic}p_s + \frac{(1+n^4)\cdot A_1 \cdot L}{2(1+n^2)(1+n^3)E}\dot{p}_{Li} \tag{3}$$

$$A_1 p_{Li} = F_{ai} + F_{fi} \tag{4}$$

where $\boldsymbol{M}(\cdot)$ is a 6×6 mass matrix, $\boldsymbol{C}(\cdot)$ is a 6×6 centrifugal terms, $\boldsymbol{G}(\cdot)$ is the gravity term, $\boldsymbol{J}_{l\bar{q}}(\cdot)$ is a 6x6 Jacobian matrix between generalized velocity of the moving platform and actuator velocity, $\boldsymbol{F}_L$ is a 6x1 actuator output force vector, $\dot{\bar{\boldsymbol{q}}}$ is the generalized velocity in inertial frame, $\boldsymbol{q}$ is generalized pose of the moving platform of hydraulic parallel industrial robot, q_{Li} is load flow, w is area gradient, x_{vi} is valve position, ρ is fluid density, p_s is supply pressure, A_1 is effective acting area of piston, c_{tc}, c_{tic} are the leakage coefficients, p_{Li} is load pressure, E is bulk modulus of fluid, c_d is flow coefficient, n is the ratio of area, $n = A_2/A_1$, F_{fi} is joint space friction.