Bilateral Control of Hydraulic Servo System Based on SMCSPO for 1DOF Master Slave Manipulator

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Abstract

In this research reaction force estimation method based on Sliding mode control with sliding perturbation observer (SMCSPO) of a hydraulic servo system for one degree of freedom (DOF) master-slave manipulators is proposed. The reaction force at the end effector of slaver is estimated by sliding perturbation observer (SPO) without using any torque sensor. This research verifies through simulation and experiment that slaver can follow the trajectory of the master device using the proposed bilateral control strategy to give a reference and estimate reaction force from observer.

Keywords: SMCSPO, Bilateral control, Master-Slave, Hydraulic servo system, Nuclear Power Plant.

1. Introduction

There are more than 450 nuclear power plants in the world, 210 in Europe and 24 nuclear power plant in the domestic have been operated. Generally lifetime of a nuclear power plant is 30-60 years, the removal of an aging nuclear power plant is being exaggerated as important problem. 150 nuclear power plant operating had been stopped permanently in 19 countries. 19 nuclear power plants completely dismantled, 100 nuclear power plants are being dismantled and 31 nuclear power plants are due for dismantling in the world [1-2]. Demand for dismantling of nuclear power plant is being continuously increased and the International Atomic Energy Agency (IAEA) predictable the market value of the nuclear facilities dismantling to be about 1 trillion dollar market by 2050 [3].In conventional bilateral control architecture, many studies have used force sensors to detect external force. However, the use of force sensor is the cause of some problems. Robot system with a force sensor is regarded as a two mass resonant system, it is difficult to realize high frequency force sensing [4-5]. Therefore, in this research we use sliding mode control with sliding perturbation observer (SMCSPO) to estimate the reaction force of the slaver and bilateral control of hydraulic servo system for 1DOF master slave
manipulators. The reaction force of slaver is estimated by sliding perturbation observer (SPO) without using any sensor. The remaining part of the paper is organized as follow: Section 2, describe the structure and dynamics of 1DOF hydraulic servo system used in dismantling power plant. In section 3, reaction force estimation method based on sliding mode control with sliding perturbation observer (SMCSPO) is discussed. Section 4, describe the bilateral control between master and slave for 1DOF hydraulic servo system. Section 5, Performance of the estimated reaction force and bilateral control is evaluated by experiments. Section 6, conclude the work.

2. Structure and Dynamics of 1DOF Hydraulic Servo System

Hydraulic servo systems are heavily used in high performance applications such as the machine-tool industry. Examples are material handling, mobile equipment, plastics, steel plants, and automotive testing. In this research the hydraulic actuators of robot for dismantling a nuclear power plant are consist of two hydraulic cylinder and one AC servo motor. Vertical movement required a greater force as compared to horizontal movement in dismantling power plant structure. In this research we use only end effector of 3DOF hydraulic servo system. Size, shape and structure is shown in fig 1 of 1DOF hydraulic servo system used in dismantling nuclear power plant.

Fig. 1 1DOF hydraulic servo system

The dynamics of a robot describe the relationship between forces, torques and motion. The general dynamic equation of a manipulator in free space is described by

\[
T = A(\theta)\ddot{\theta} + B(\theta, \dot{\theta}) + g(\theta)
\]  

(1)

Where \( \theta \), \( A(\theta) \), \( B(\theta, \dot{\theta}) \), \( g(\theta) \) and \( T \) are the vector joint of angles, the mass/inertia matrix, the centrifugal/coriolis torque, the gravity torque in joint space, and the vector of joint torques, respectively. The dynamics equations of each link of hydraulics servo system are as follow

\[
(J_1 + \Delta J_1)\ddot{\theta}_1 + (D_1 + \Delta D_1)\dot{\theta}_1 + \beta_1\dot{\theta}_1 + 0.5M_1g\sin\theta_1 + \tau_e = \tau_1
\]  

(2)

In above equations, \( J_1 \) is the inertia, \( D_1 \) is damper, \( \Delta \) shows the uncertainty of parameters, \( \beta_1 \) is viscosity of cylinder, \( M_1 \) is mass, \( L_1 \) is length, \( \tau_1 \) is reaction torque by contact with environment, \( \tau_e \) is joint torque of link 1, \( \lambda \) is dynamics effect from link 1, \( \dot{\theta}_1 \) is viscosity friction of cylinder 1.

3. Sliding Mode Control with Sliding Perturbation Observer (SMCSPO)

The three links manipulator robot actuator is controlled by sliding mode control (SMC) and reaction force is estimated by sliding perturbation observer (SPO). The governing equation for general second order dynamics with n-degree-of-freedom (dof) is:

\[
\ddot{x}_j = f_j(x) + \Delta f_j(x) + \sum_{i=1}^{n}(b_{ji}(x) + \Delta b_{ji}(x))u_i + d_j(t)
\]  

(3)

Where \( x \triangleq [X_1, ..., X_n]^T \) is the state vector and \( \dot{x}_j \triangleq [\dot{x}_j, \ddot{x}_j]^T \). The terms \( f_j(x) \) and \( \Delta f_j(x) \) correspond to the nonlinear driving terms and their uncertainties. The component \( b_{ji} \) and \( \Delta b_{ji} \) represent the elements of the control gain matrix and their uncertainties, while \( d_j \) is the external disturbance and \( u_i \) is the control input. The terms \( f_j \) and \( \dot{b}_{ji} \) are known continuous functions of the state \( [6] \). Estimated perturbation is defined as the combination of all uncertainties.

3.1. Control Variable Transformation

Before integrating SO into SMC it is convenient to decouple the control variable using the following transformation \([7]\).

\[
f_j(\tilde{x}) + \sum_{i=1}^{n}b_{ji}(\tilde{x})u_i = \alpha_{3j}\tilde{u}_j
\]  

(4)

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Where $\alpha_{3j}$ is an arbitrary positive number and $\ddot{u}_j$ is the new control variable. The original control vector of general equation is obtained as
\[
u = B^{-1}C_{\alpha_j} [\alpha_{3j} \ddot{u}_j - f_j(x)]
\]
(5)

Where $\nu = [\nu_1, ..., \nu_n]$ and $B = [b_{j1}(x)_{max}$. This transformation allows to write the system dynamics as
\[
\ddot{x}_j = \alpha_{3j} \ddot{u}_j + \psi_j
\]
(6)

4. Bilateral Control between Master and Slave for 1DOF Hydraulic Servo System

In this research 1DOF hydraulic servo system for master and slave is considered. The dynamics equation of master and slave for hydraulic servo system are described by
\[
J_m \ddot{\theta}_m + B_m \dot{\theta}_m = u_m + \tau_h
\]
(7)
\[
J_s \ddot{\theta}_s + B_s \dot{\theta}_s = u_s - \tau_e
\]
(8)

Where $J_m, J_s, u_m$ and $u_s$ are inertia, position and control input of master and slave of hydraulic servo system, respectively. Action force generated by operator while maneuvering the master device is denoted by $\tau_h$, while reaction force appears when slave device is touching remote environment is defined by $\tau_e$. The structure of bilateral controller is shown in fig. 2.

Fig. 2 Bilateral control structure

Slaver of hydraulic servo system is follow the trajectory of master device when operator operate the master device.

5. Experiments and experimental results

Experiments were performed on 3DOF hydraulic servo system. Master and slave device consist of three links each, in which third link connected with base. We can find the reaction force at the end effector. The whole system for experiment includes master device, slave device and a control system as shown in fig 3.

Fig. 3 System for experiment

5.1. Experimental results

The experiment was conducted on a three-link hydraulic servo system. In Fig. 4 shows the experimental result of reference (Master) and end-effector (Salver) trajectories. In Fig. 4 the reference trajectory is shown in blue line and end-effector trajectory shown in red line.
6. Conclusion
This research proposed an estimation method of a reaction force on end effector of one links robot manipulator using SMCSPO without using any sensor. The estimated perturbation showed the uncertainty of dynamics and reaction force. However, it is useful to find the reaction force where the reaction is big enough and not easy to use the sensor such as transportation of active uranium in nuclear power plants or disposal of explosive ordnances, remote cutting for nuclear power plant dismantling, debarring, welding and grinding etc. In future research, other factors may also be included to improve the accuracy of force estimation.

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References

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