Hardware in loop Simulation for Hydraulic Stewart Master-Slave System

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Abstract. A hardware in loop (HIL) simulation platform for a hydraulic Stewart master-slave system used for curved surface grinding work is developed. The communication between hydraulic Stewart force feedback joystick and the computer is realized by AD/DA card, which was used to improve and evaluate the performance of the real controller. The software built by MATLAB/simulink in the computer includes the functions such as the master cylinder controller, the slave hand virtual plant the slave cylinder controller and the bilateral controller, which is applied to improve and evaluate the performance of the real controller. A workspace based control strategy was performed to validate the system.

Introduction

HIL simulation is a dynamic test technique that provides a simulated environment for the real controller (hardware) under test, simulating the parts of the system that are not physically present with real-time plant model (software). Today, due to progress in digital computer technology, most control algorithms are implemented by embedded systems and through programming codes in a digital manner. Sensors are responsible for measuring the system output parameters[1,2,3]. Therefore, an HIL simulation platform which may simulat a full-scale model of the system is of great requirement.

Stiffness; therefore, studies are now focusing on hydraulic actuators. The hydraulic force feedback manipulator differs from electronically actuated ones in that the force or torque output is not proportional to the actuator current, and therefore, the force feedback control method differs considerably. Kudomi and Yamada established a hydraulically driven Stewart master-slave force feedback system [4,5,6]. Chen [7] and Hou [8] used an F-P algorithm to develop a new force feedback control method for a hydraulic force feedback system with 2-DOF hydraulic joysticks as a master hand and an engineering robot as a slave hand. Force-feedback manipulators actuated by electric motors do not provide adequate position accuracy and feedback force

An HIL system is developed for the hydraulic Stewart master-slave system, which may shorten development cycle, improve reliability and quality of the controller, is presented. In this paper, we introduced the HIL system in Section 2, and then the HIL software in simulink platform was introduced in Section 3; an experiment is complemented to test its function in Section 4.

The HIL Platform

System Description

Figure.1 shows the HILplatform of the hydraulic Stewart force feedback master-slave control system. The master site shown in the left figure is a hydraulic Stewart force display. Linear displacement sensor is mounted on each hydraulic cylinder for feedback of position controller. Six linear force sensors are mounted on the hydraulic cylinders to sense the rod force. By the method of force compose; the six-dimensional force on the platform which represents the operator force is got. The displacement and force signals are sent to the PC computer through serial AD card while the control signal to the servo valve of each hydraulic cylinder is generated by the PC computer and send to the joystick by DA card.

The software in the computer includes the virtual plant of the slave hand, the master-slave control algorithm and the environment force. The force and displacement signals in the AD card are got by an S function file in the simulink program by serial data communication, so does the control signals to the DA card. Serial baud rate is 9600 bytes/s, the sampling rate is 100times/s.

The virtual plant is programmed according to the real mechanic. The master-slave controller includes the master cylinder, the slave cylinder controller and the master-slave control framework. Both the master and slave cylinder controller are designed by a Simulink S function, which can be transform to C code by RTW（real-time workshop） for the real controller. The feedback master-slave control system for the hydraulic Stewart force consists of the operator, master hand, communication links, slave hand, and external environment.

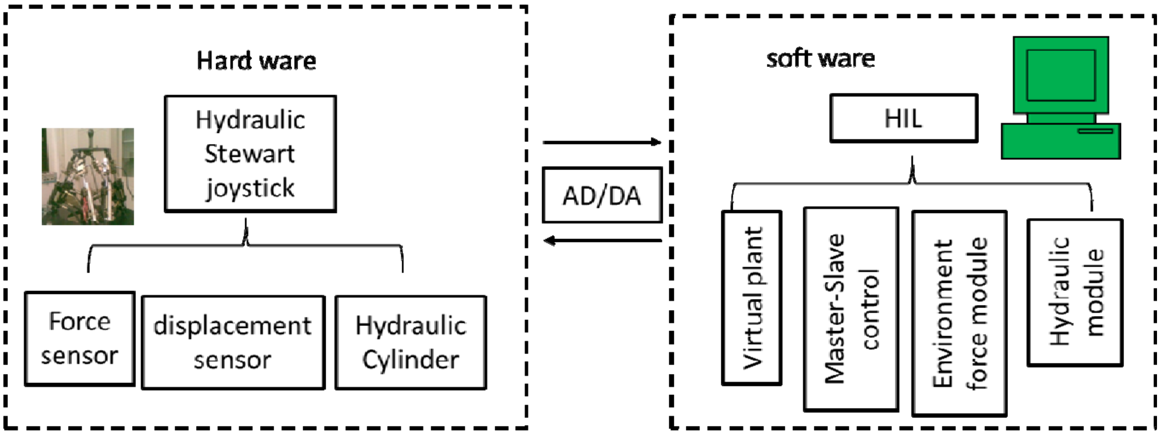


Figure.1. The HIL system

Master-Slave Control

Figure.2 shows the overall control architecture of a work-space-based four-channel master-slave control strategy, which is designed according to the mechanical structural characteristics of the hydraulic Stewart master-slave system. This strategy can ensure effective force feedback by using a linear force sensor installed on the cylinders.

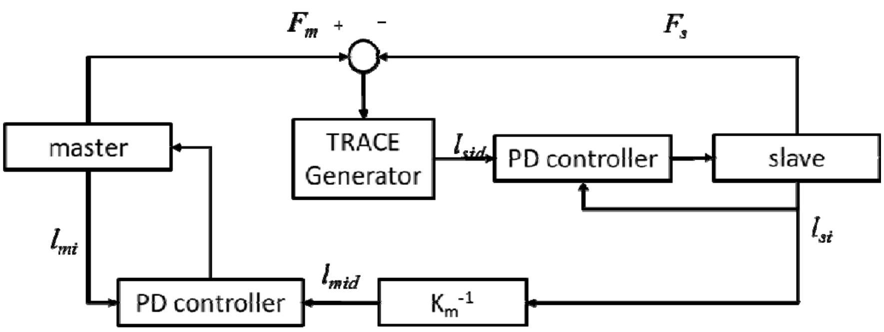


Figure.2. Master-slave controller

The work-space-based four-channel control algorithm achieves complete master-slave force feedback control. It involves three steps. First, a comparison is made between the operator's force at the master site and the environment force at the slave site. These two forces are calculated by a force Jacobian based on the cylinder force measured by the force sensor. The error of the two forces can be used as a control signal to generate the desired displacement of the slave platform.

In the slave platform's position controller, the error of the master platform force and slave platform force is transformed to the desired displacements of the slave cylinders by inverse kinematics. This, in turn, is used to drive the slave platform using the position controller with position feedback, and a PD controller is used to ensure position accuracy in consideration of the force output limit.

The motion-following controller enables the master platform to track the slave platform. The orientation of the slave upper platform is calculated by forward kinematics and passed to the master site by implementing the following motion from the master platform to the slave platform using the PD controller.

The Soft Ware Design

Software Overall Structure

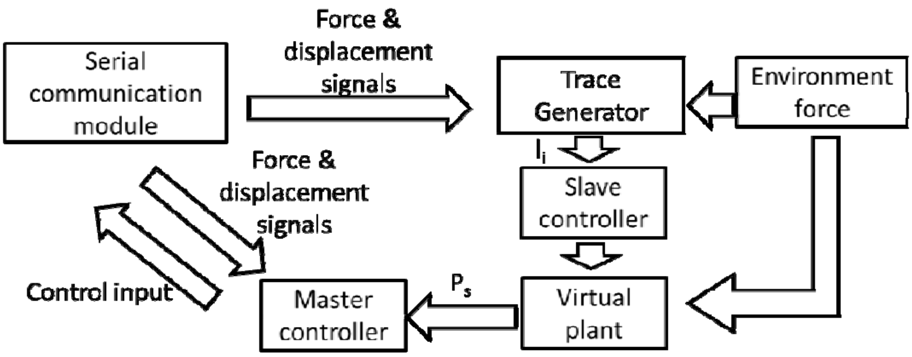


Figure.3. The software overall structure

The overall structure is shown in Figure.3. the master force and displacement signals are collected by serial communication modules. The disired trace of the slave cylinder lsid (i=1~6) are generated in the trace generator according to the signals and the environment force from the environment force module. Then slave controller bring trace following control to the virtual plant. The master hand should follow the orientation and the force of the upper platform of the slave virtual plant (Psi, Fsi), which are realized in the master controller.

The Hydraulic Module

The hydraulic system in the virtual plant is a servo valve controlled cylinder. It's dynamic can be descripted as the following equations

$$\frac{d^2x}{dt^2}+2\zeta\omega_n\frac{dx}{dt}+\omega_n{}^2x=k_v\omega_n{}^2i \quad (1)$$

$$m\ddot{y}_s+b\dot{y}_s=a_p p_L \quad (2)$$

$$q_L=k_x x-k_p p_L \quad (3)$$

Where ap is cross-sectional area of piston; b is Viscous damping coefficient of piston; ka is Gain of servo amplifier;kx ,is Flow rate gain[m2/s], kp is pressure gain [m4/kg];kv is Gain of servo valve [m/mA]; qL Flow rate[m3/s],pL is load pressure [Pa] ;u is Control input [V] ;xis Displacement of spool[m]; ζ is Damping ratio; ω_n is Natural angular frequency [rad/s].

Eq. (1) is the motion of the servo valve. Eq. (2) is the motion of the piston. Eq (3) is the relations between the servo valve and the flow rate.

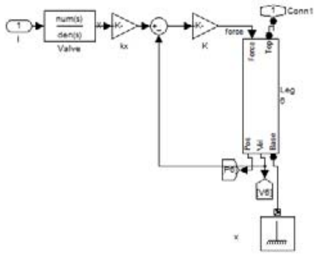


Fig.4 The hydraulic cylinder simulation

To simulate the hyraulic cylinder in simulink/simmechanics, the force of the spool should be generated according to the control volt of the servo valve and the cylinder speed signal. Then the force is output to the leg cylinder.

Environment Force Module

The environment force module functions as simulating the environment force acts on the slave virtual plant. The enviorment force is realized by an S-function module and a force actuator module in simulink. Three types of space force including the force and torque in Cartesian coordinate system are generated:

(1)The dynamic model built in simulink, which can be used in simulation operating;

(2)The lookup table module of the space force from the 6 dimension sensor coord to the space motion, which functions during the on-line virtual operate;

(3)The space force in a perion of time to realize the reappear of the work condition.

The Upper Platform Force

Normally, the space force on the upper platform of the slave virtual plant should be realized according to the dynamic of the Stewart mechanical[9] according to

$$J\begin{bmatrix} \ddot{t} \\ \alpha \end{bmatrix} + \eta = HF + \begin{bmatrix} \chi & F_{ext} \\ \chi & M_{ext} \end{bmatrix} \quad (4)$$

The parameters in (4) is shown in [9].

As the slave plant works in a low speed, the slave force are realized by the amount of the static force Jacobian and environment force for simplifying consideration.

$$M_s = M + M_e \quad (5)$$

where Ms is the space slave force, Me is the environment space force and is the static Jacobian.

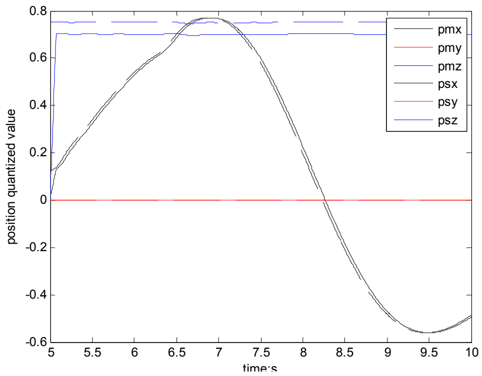
$$M = Gf \quad (6)$$

where $M = \begin{pmatrix} F_x & F_y & F_z & T_x & T_y & T_z \end{pmatrix}$, $f = f_i(\mathrm{i} = 1 \sim 6)$,GT=J-1.

Experiment

To validate the function of the HIL system. An experiment simulation operating is emplemented. In the experiment, the operator push the master joystick to move in x direct. The environment force in the experiment force is a virtual horizontal wave force. And the act position is at the center point of the slave upper platform. Figure.4 shows the position experiment result of the master and slave hand.

Figure.5 shows the master force and the slave environment force. To decrease the difference of the two Stewart platform, both the position and force result values are quantized value.



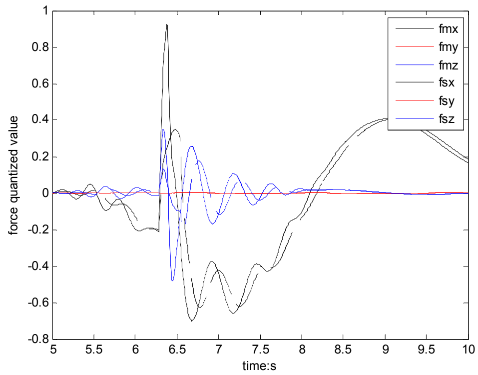


Figure.5. The position experiment result   Figure.6 .The master force and the slave environment force

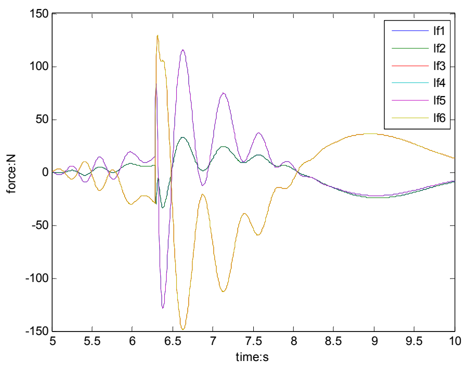


Figure.7. The slave leg force

The result indicates that the master hand can effectively tracks the slave displacement and the master force has a good corresponding relationship with the slave environmental force. Thus the operator can feel the change from the environmental force and realize precise operation. The function of the master-slave operation of the is realized by the HIL system.

Figure.6. shows the slave leg force. The result shows that the virtual plant can effectively simulates the dynamic character of the real plant.

Conclusions

This study addresses the HIL system of a hydraulic Stewart master-slave system. The overall system and a master-slave control algorithm are described. The software modules such as the hydraulic module, the environment force module and the upper platform force are clarified. A simulation operation experiment is immpletemented. The HIL simulation approach ensured that the master-slave control system may experiment in low cost. More research work is required in the future.

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