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Control of a Decommissioning Hydraulic Manipulator using Time Delay Control

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1. Introduction

Robot technologies can play a major role in decommissioning nuclear reactor because nuclear power plants have high levels of radiation and limit a human access. Specially, manipulator systems are useful for dismantling complex structure in a nuclear facility. In addition, the nuclear decommissioning industry has required the techniques of handing heavy-duty objects. For this reason, we applied a hydraulic system that can generate great power.

However, the control of hydraulic manipulator is difficult from the standpoint of the following problems: parameter variation in mechanical structures and various nonlinearities in hydraulic actuators. In mechanical structures, the inertial force and gravitational force varies largely with joint motions. Hydraulic actuators, massively coupled and complexly connected, have various nonlinear components such as hysteresis, dead-zone, friction and other unknown nonlinearities.

To solve these problems, several research works have been performed. In the study for system of over three degrees of freedom, Chang and Lee used time-delay control(TDC) and compensators based on the dynamics of hydraulic excavator and validated good performance[2]. Lee and Chang proposed time-delay control with switching action using integral sliding surface and applied hydraulic excavator[1]. Looking at these studies, the TDC is useful to control hydraulic systems.

In this paper, we applied time-delay control to the control of a decommissioning hydraulic manipulator and verified control performance through experiments on a circular motion tracking control.

2. Decommissioning hydraulic manipulator

2.1 Developed hydraulic manipulator

To dismantle nuclear reactor, we developed a hydraulic manipulator with six degrees of freedom and R-T-R-R-R-R structure as show in Fig. 1. The D-H parameters were listed in Table. 1. The developed hydraulic manipulator has a full extension reach of 3.2m and a payload of 250kg. We developed the manipulator to have a non-spherical wrist structure for a large workspace and dexterity. A typical wrist of a manipulator can be classified into a spherical wrist, where three axes meet at one point, and a non-spherical wrist, where three axes do not meet at one point.

Fig. 1 A decommissioning hydraulic manipulator

Table I: D-H parameters of a hydraulic manipulator

Axis	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	$-\pi/2$	0	$1.329m+\theta_2$	$-\pi/2$
3	$-\pi/2$	0	0	$\theta_3-\pi/2$
4	0	0.502m	0	θ_4
5	$-\pi/2$	0.482m	0	$\theta_5-\pi/2$
6	$-\pi/2$	0	0.9291m	θ_6

2.2 Hydraulic actuator

We selected two hydraulic motors that are OMM40 and OMP80 models of Danfoss Ltd, Inc. The OMM40 model has a maximum torque of 45 Nm and a maximum speed of 500 rpm. The OMP80 models has a maximum torque of 150 Nm and a maximum speed of 770 rpm. To satisfy the required torque, we chose a harmonic reducer with a 160:1 gear ratio. For the required force of translational modules, we selected a linear guide with a lead of 5 mm. The specification of the hydraulic actuators were shown in Table 2. The hydraulic supply unit offers a pressure of 210 bar and a flow of 60 lpm.

Table 2: Specifications of hydraulic actuators

Revolute		Translational
OMM40 40Nm 500rpm	OMP80 150Nm 770rpm	OMM40 40Nm 500rpm
Harmonic Reducer (160:1)	Harmonic Reducer (160:1)	Linear Guide (5mm/rev)
5, 6 axis	1, 3, 4 axis	2 axis

3. Time Delay Control(TDC)

To increase control performance in hydraulic system, the TDC has been applied[1-2]. The robot dynamic equation can be assumed such as

$$\bar{\mathbf{M}}\ddot{\mathbf{q}}(t)+\bar{\mathbf{H}}(t)=\mathbf{u}(t) \qquad (1)$$

Note $\bar{\mathbf{M}}$ is a constant matrix, $\bar{\mathbf{H}}(t)$ consist of terms representing uncertainties and time-varying factors. We define the desired dynamics of the closed-loop system with the following error dynamic equation:

$$\ddot{\mathbf{e}}(t)+\mathbf{K}_v\dot{\mathbf{e}}(t)+\mathbf{K}_p\mathbf{e}(t) \qquad (2)$$

Where $\mathbf{e}(t)$ is the position error vector, $\mathbf{K}_v$ is derivate gain matrix, $\mathbf{K}_p$ is the proportional gain matrix. The TDC law that meets the requirement is obtained as

$$\mathbf{u}(t)=\bar{\mathbf{M}}[\ddot{\mathbf{q}}_d(t)+\mathbf{K}_v\dot{\mathbf{e}}(t)+\mathbf{K}_p\mathbf{e}(t)]+\hat{\mathbf{H}}(t) \qquad (3)$$

Where $\hat{\mathbf{H}}(t)$ is an estimation vector of $\bar{\mathbf{H}}(t)$. The estimated $\hat{\mathbf{H}}(t)$ can be obtained by using both Eq.(1) and the fact that $\bar{\mathbf{H}}(t)$ is usually a continuous function. More especially, when L(sampling time) is small enough then

$$\hat{\mathbf{H}}(t)\approx\bar{\mathbf{H}}(t-L)=\mathbf{u}(t-L)-\bar{\mathbf{M}}\ddot{\mathbf{q}}(t-L) \qquad (4)$$

Combining Eq.(4) with Eq.(3), the TDC law is obtained follows:

$$\mathbf{u}(t)=\mathbf{u}(t-L)+\bar{\mathbf{M}}[\ddot{\mathbf{q}}_d(t)-\ddot{\mathbf{q}}(t-L)+\mathbf{K}_v\dot{\mathbf{e}}(t)+\mathbf{K}_p\mathbf{e}(t)] \qquad (5)$$

More details about the stability condition and the design of TDC can be found in Youcef-Toumi and Ito(1990) and Hsia and Gao(1990). Figure 2 shows control scheme of decommissioning hydraulic manipulator using TDC.

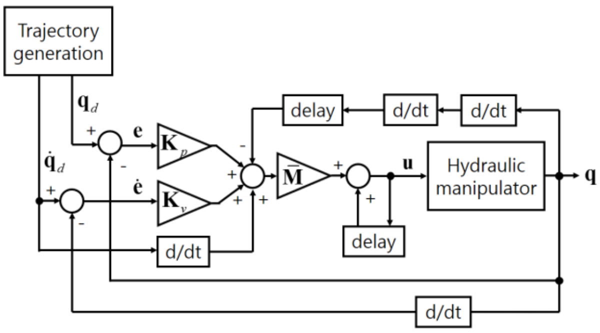

Fig. 2 Control block diagram using TDC

4. Experiments

The circular motion tracking control was performed to confirm the control performance. In experiments, the circular trajectory of the end-effector is the radius of circle of 300mm and the speed of 5deg/sec. The hydraulic supply unit offers a pressure of 140 bar.

Figure 3 shows experiment result at 3D workspace. The RMS error of x position is 0.68 mm, the RMS error of y position is 0.1mm and the RMS error of z position is 0.67mm.

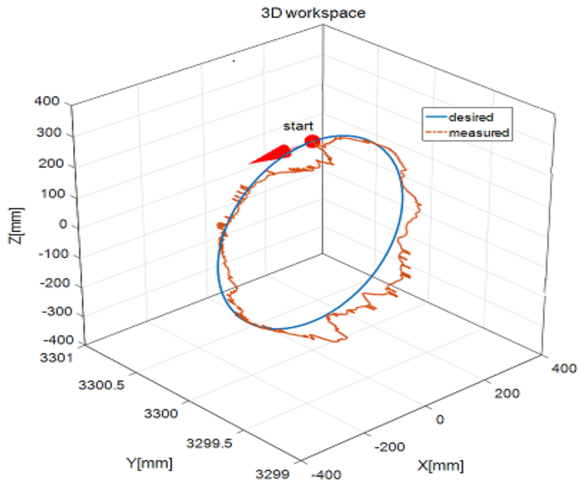

Fig. 3 Tracking control performance of circular motion

5. Conclusions

In this paper, the TDC was applied to precisely control for decommissioning hydraulic manipulator. To verify control performance, the circular motion tracking control has performed.

From the experimental result of applying TDC to hydraulic manipulator, the distance error of the end-effector is mostly within ±0.7mm. The results verify good tracking performance.

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