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Hardware-in-the-loop Simulator of Hydraulic Manipulator System for Decommissioning Nuclear Power Plant

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Abstract

Recently, many nuclear power plants have reached the end of their lives all over the world. The need for decommissioning nuclear power plants is increasing. The core facilities of nuclear power plants are very large, heavy, and contaminated radioactively. To deal with such a dangerous work to dismantle nuclear power plants, unmanned solutions such as robotic technologies are mostly applied. The hydraulic system has a high ratio of power to weight, and the manipulator system can be an effective solution for narrow areas. Thus, the hydraulic manipulator system is widely used in decommissioning applications [1].

In order to effectively develop the hydraulic manipulator system, it is necessary to identify problems with repeated experiments for improving system performance. However, physical experiments require a huge amount of time and cost. The hardware-in-the-loop simulation (HILS) test can be an effective solution. The HILS test can realize the dynamic characteristics of the system and verify the control system algorithm by implementing various situations in the virtual environment. Thus, the performance of the system can be improved more effectively by using the HILS simulation.

In this paper, a real-time simulator was studied for the HILS test of the hydraulic manipulator system for decommissioning nuclear power plants. For real-time analysis in HILS, a manipulator dynamics model was developed by using a multibody recursive formulation [2], and a virtual model of a hydraulic manipulator system was developed by adding a nonlinear model of a hydraulic system [3]. Since the hydraulic system includes stiff characteristics, an implicit integration method is applied for the stable solution with a larger integral step. Moreover, the real-time analysis should guarantee the same amount of calculation for each integration step. Thus, a non-iterative HHT-α integration method [4] was chosen to improve the accuracy of the solution without the iterative method.

Figure 1 shows the HILS simulator of the hydraulic manipulator system. The electronic control unit (ECU) system was constructed through the servo valve controller based on the ARM embedded processor and the real servo valve manifold that controls the fluid. Then, the dynamic model of the hydraulic manipulator system and the robust numerical integration method for real-time analysis were implemented to the host PC. The host PC and the servo valve controller exchange information through ethernet-based UDP communication.

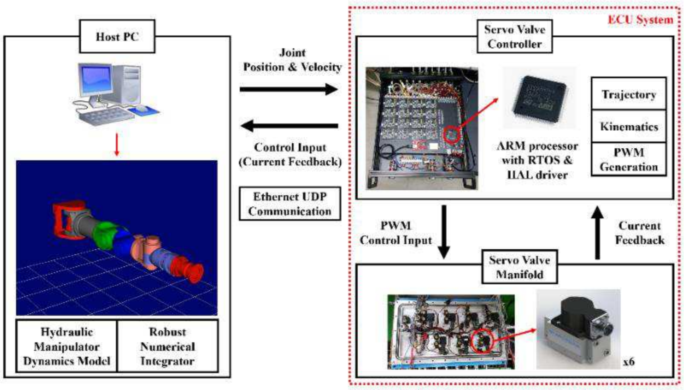

Figure 1: Configuration of hydraulic manipulator HILS simulator.

To verify the performance of the developed HILS simulator, as an example, a simulation in which the end-effector of the hydraulic manipulator system follows a circular trajectory in Cartesian space was carried out as shown in Fig. 2. The circular trajectory used in simulation has a radius of 300mm, and the end-effector of the hydraulic manipulator system is to follow with a speed of 7.5deg/sec. Also, to compare real-time performance, the computational time and the accuracy of the solution were compared with those from the explicit integrators, which are commonly used such as Runge-Kutta 4th order and Adams-Bashforth 3rd order methods.

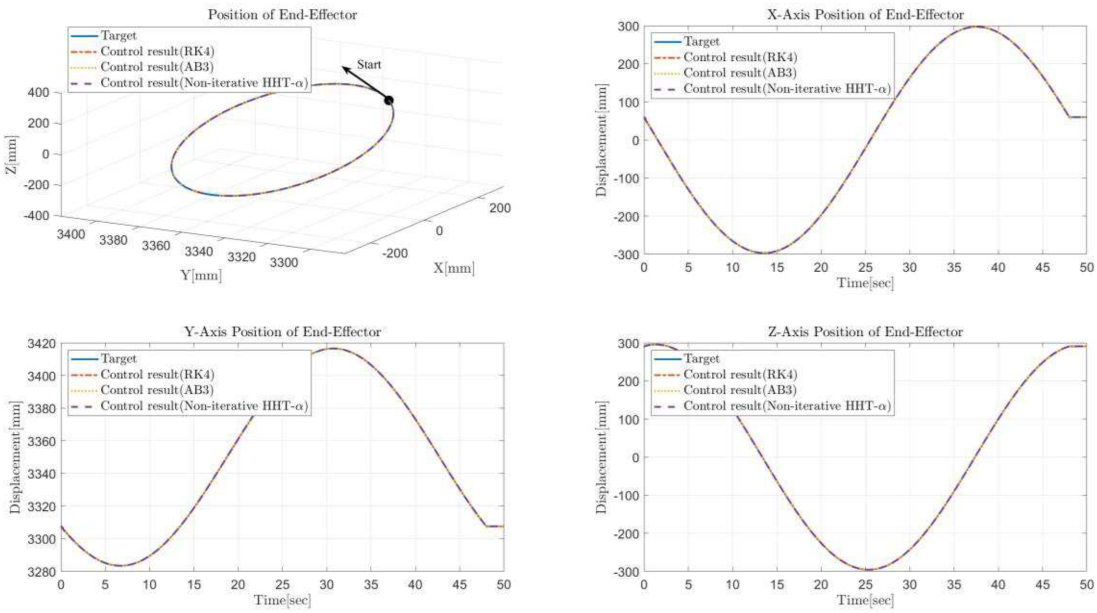

Figure 2: Simulation results of circular trajectory following

Table 1: Efficiency and accuracy of circular trajectory following simulation.

Integrator	Step size [msec]	Computational Time [msec]	Position Control RMS Error [mm]		
			X-Axis	Y-Axis	Z-Axis
Runge-Kutta 4th	0.01	288.476706	0.207598	0.040390	0.084689
Adams-Bashforth 3rd	0.01	103.679508	0.207582	0.040388	0.084682
Non-iterative HHT-α	0.1	75.061573	0.207630	0.040373	0.084678

As a result of the simulation, when the non-iterative HHT-α integration method is used, the integral step size is increased 10 times compared to the explicit integration method, and the computational time is also the fastest. The position RMS error of the end-effector is almost the same. Therefore, the HILS test is realized in real-time using the developed HILS simulator of a decommissioning hydraulic manipulator system.

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