

Environmental Management Science Program

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Development of Monitoring and Diagnostic Methods for Robots Used in Remediation of Waste Sites

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Research Objective

Safe and efficient clean up of hazardous and radioactive waste sites throughout the DOE complex will require extensive use of robots. This research effort focuses on developing Monitoring and Diagnostic (M&D) methods for robots that will provide early detection, isolation, and tracking of impending faults before they result in serious failure. The utility and effectiveness of applying M&D methods to hydraulic robots has never been proven. The present research program is utilizing seeded faults in a laboratory test rig that is representative of an existing hydraulically-powered remediation robot.

Research Progress and Implications

This report summarizes activity conducted in the first 9 months of the project. The research team has analyzed the Rosie Mobile Worksystem as a representative hydraulic robot, developed a test rig for implanted fault testing, developed a test plan and agenda, and established methods for acquiring and analyzing the test data.

The test apparatus consists of a hydraulic power supply system (HPSS) and actuators which are representative of typical components on Rosie. The HPSS includes a 30 kW (40 hp) electric motor drive, capable of providing 75 l/min. at 208 bar (20 gpm at 3000 psi). It is packaged as a single unit with a sump, filters, heat exchanger and circulating pump, accumulator and safety release and pressure control valves. Fluid from this supply flows past another accumulator and through a control valve into the actuator, and then to the system.

The test actuator is a Black Bruin Model 404-080-2111 hydraulic motor. It is a radial piston design and has a maximum power rating of 35 kW (47 hp), a maximum output speed of 185 rpm and can deliver a torque of 2990 Nm at 250 bar (2200 ft-lb. at 3600 psi). In Rosie, this motor directly drives a road wheel and carries the wheel load. For our tests, the motor output shaft is subjected to the loads it would see in service, namely a load equivalent to the nominal weight on the wheel and a torque to resist motion. Radial load is provided by an adapter and a hydraulic jack assembly, and torque is applied by an identical motor, used as a pump, in a "back-to-back" arrangement. The torque loading pump is fed through a separate hydraulic supply consisting of a low-pressure pump, cooler and reservoir. Load will be controlled by means of a throttling valve, with a relief valve to prevent overpressure. The test rig design is complete and fabrication is underway.

A Test Plan has been prepared that describes the test system, the failure issues associated with hydraulically actuated robot subsystems, the applicable portions of Rosie, the methodology used to select and simulate the faults to be implanted, the plans for data acquisition, system control and data reduction, and a test matrix and procedure. The faults to be implanted have been selected and ranked based on importance (criticality and likelihood), ease of implementation and risk to the test apparatus. The fault list, in ranked order, includes: ruptured pressure supply line, HP pump internal leakage, loss of oil cooling, sticking control valve, control valve open winding, motor encoder feedback loss, internal leak in wheel motor, HPSS pump drive motor fault, broken relief valve spring, loss of accumulator charge, scored HP pump housing, plugged HPSS high side filter, and damaged piston in wheel motor. The actual number of these faults to be implemented will depend on the ultimate complexity of the testing, in order to extract the data needed to characterize each fault reliably.

Methods for data reduction and fault detection include model-based assessments, vibration analysis, temperature and pressure tracking, and a fuzzy expert system. The model-based approach

will utilize Analytical Redundancy (AR) to compare signals from the physical system to a real-time simulation of the system. AR is a model-based technique that derives the maximum number of independent tests of the consistency of sensor data with the nominal model and past sensor control input streams. When the system is operational, the parameters of the model will be tuned from nominal values by examination of data streams without implanted faults. Then the data streams from runs with implanted faults will be used to characterize the error signals generated by each type of fault. A fuzzy expert system will be developed to recognize these signals and reject random noise. This will then be tested by running the compiled data reduction system in parallel with the test bed, processing the sensor data in real time, to test and improve its efficiency.

Additional fault detection methods will be implemented and integrated with the expert system. Certain sets of signals such as line pressure, fluid temperature, or tank level, are important fault indicators with minimal processing. The AR techniques should detect many of these faults as well, allowing confirmation of such. Frequency domain vibration analysis of accelerometer data has proven it's worth as a fault detection method, and the existing knowledge of the team in this area will be helpful. Additional methods may be investigated as the project proceeds to add redundancy or cover areas where the planned techniques show inadequate performance.

Planned Activities

The remaining parts for the test rig will be fabricated and the final assembly completed this Summer. Following rig commissioning, an initial series of baseline and implanted fault tests will be conducted. Our plan is to interactively conduct tests, data reduction and diagnostic methodology development so that subsequent tests can be adjusted based on the analysis of data from the initial evaluations.