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

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Executive Summary

In the Environmental Restoration and Waste Management Program of the Department of Energy (DOE), extensive use of robots is planned for safe and efficient clean up of hazardous and radioactive waste sites. Robots operating at these waste sites will be exposed to a variety of life-limiting environmental and operational conditions. Undetected faults in these robots can have serious consequences including damage to the waste containment facilities by the faulty robot, complete or partial failure of the robots which could result in delays in the clean up activities, or in extreme cases could result in loss of the robot.

In this research proposal, to avoid the dangers associated with in-operation failure of robots, Mechanical Technology Inc. (MTI) and Rice University (RU) propose to develop Monitoring and Diagnostic (M&D) methods which would provide for early stage detection, isolation, and tracking of developing faults before they result in serious failure. Efficient M&D methods developed in this research would help the DOE personnel in reducing the risk of catastrophic in-site robot failures and thereby decrease the risk of damaging the containment facilities, loss of robot, and mission failures. By avoiding the additional time and cost required for post-robot-failure clean up, the M&D methods will help in providing for faster, safer, and less expensive clean up.

To perform M&D of robots, presently there are several applicable methods available in the literature which have been proven to provide early detection of incipient faults. However, all of these methods are limited in application to electrically driven robots. The utility and effectiveness of these methods in application to remediation robots, which are typically hydraulic in nature, have never been proven. The research in this program will be a pioneering effort for developing efficient M&D methods for hydraulic robots, with applications to a wide variety of robots including remediation robots, multi-arm manipulators, and industrial robots.

The work in this program is based on the extensive study undertaken in a different DOE program to analyze the M&D needs of remediation robots. In this study, the Rosie Mobile Worksystem, developed by RedZone Robotics and Carnegie Mellon University for operation in nuclear environments was selected as a reference. A failure modes and effects analysis was performed to identify various failure modes due to environmental and operational conditions, their cause and effect on the overall system performance, and the criticality, speed, and probability of failures. This analysis indicated that faults in the Hydraulic Power Supply Subsystem (HPSS) and the Tether Drive Subsystem of Rosie were the most critical for which M&D methods are needed. In the research, these M&D methods will be developed by assembling a test rig at MTI test laboratories for performing seeded-fault experiments. This test rig will be composed of a HPSS and an Actuator Subsystem which is representative of most of the typical actuators in Rose. A variety of faults originating due to radiation, corrosion, dust, fluid contamination, etc. will be installed in the test rig, and signals from nine different sensors will be used to provide early detection of faults.

To develop efficient M&D methods for remediation robots, the research will address two main challenges: (1) effective differentiation of changes in sensor signals due to faults from those due to robot dynamics in presence of noise and fault signature variability, and (2) quantification of the complex interactions between various components for fault isolation. The dynamic operation of the robot changes the sensor signals making it difficult to distinguish these changes from those caused by a fault. The task is further complicated by external noise in the sensor signal and fault signature

variability due to the complex interactions between the robot and its environment. The research will investigate various dynamic model-based methods, fuzzy and dynamic thresholding methods, and pattern classification methods that can provide clear and early indication of faults in the robot by coping with robot dynamics, sensor noise, and fault signature variability. The second challenge the research will address relates to the complex interactions between various components in the robot and its environment that causes problems in differentiating the faulty components from their secondary effects. In the research, various expert system approaches based on fault trees and fuzzy knowledge representation will be investigated to identify the most effective means of identifying faults in remediation robots.