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Robot-assisted Online Monitoring, Online Maintenance, and Dynamic Risk Assessment for LWRs and Advanced Reactors

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ABSTRACT:

As one of the most significant large-scale power providing technologies of the twenty-first century, the total capacity and operational scope of nuclear energy must be increased to accommodate society's evolving energy needs while meeting environmental, clean energy and carbon-neutral goals. The sustainable and cost-effective deployment, operation, and maintenance of both current light water reactors (LWRs) and advanced reactors for current and cutting-edge use cases, such as non-base load operation and hydrogen generation, has the potential to greatly impact and improve the utilization of nuclear energy. Online monitoring and predictive maintenance have been studied over the decades as means to reduce operations & maintenance costs via the use of data-driven models to detect artifacts such as faults and equipment degradation, aiming to shift maintenance paradigms from preventative to condition-based and eliminating unnecessary downtime. However, these techniques have not been widely adopted due to uncertainty in their robustness and real-world data challenges, such as missing or unreliable data. A significant portion of maintenance program is still focused around human-centric processes such as walkdowns and visual inspections. With recent rapid technological advancements in robotics and computing, it is now feasible to use the dynamic sensing and remote manipulation capabilities of these robots to reduce repetitive work and maintenance tasks, especially in harsh environments dangerous or hostile to humans. This research will develop a robot-assisted and enabled online monitoring, online maintenance, and dynamic risk assessment framework to: (1) uses mobile robotic platforms to provide dynamic in-the-field sensor data based on the fault detection and diagnosis needs, (2) combines these dynamic sensor data streams with fixed data streams to improve situational awareness and reduce uncertainty in online monitoring, diagnostics, and risk assessment, and (3) accomplishes ancillary maintenance tasks via robotic platforms to reduce downtime. To accomplish this, a digital twin of a physical PWR facility integrated with real-time physical parameter telemetry from a full-scope, high-fidelity PWR simulation will be developed to provide a realistic environment for robotic navigation and manipulation simulations. An advanced decision-making system containing online monitoring, diagnostics, and dynamic risk assessment subsystems will be developed to provide full situational awareness for the whole power plant. Trajectory optimization and task planning algorithms will be developed to allow logical integration between the robotic platforms and this machine learning-based decision-making system. The effectiveness of the system will then be demonstrated in the simulated environment and independently evaluated via a cyber-physical testbed. This research will enable a feasible, scalable architecture for both LWRs and advanced reactors to operate safely and more economically while responding to evolving maintenance environments in a more flexible and cost-effective manner.