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NUCLEAR PROPULSION CONTROL AND HEALTH MONITORING

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Summary

An integrated control and health monitoring architecture is being developed for the Pratt & Whitney XNR2000 nuclear rocket. Current work includes fruther development of the dynamic simulation modeling and the identification and configuration of low level controllers to give desirable performance for the various operating modes and faulted conditions. Artificial intelligence and knowledge processing technologies need to be investigated and applied in the development of an intelligent supervisory controller module for this control architecture.

In recent years, there has been renewed interest in solid core nuclear thermal propulsion systems (nuclear rockets) because of their ability to achieve space mission performance objectives that are well beyond chemical propulsion system capabilities. Because the planned missions for these propulsion systems will require autonomous or nearly autonomous operation, advanced controls and health monitoring systems have been identified as critical technologies for their development.[1] The Pennsylvania State University's Intelligent Distributed Control Research Laboratory is currently defining a control system and required instrumentation for the Pratt & Whitney XNR2000 fast spectrum, CERMET fueled nuclear rocket.[2] The project includes development of simulation models to evaluate various control algorithms, application of recent advances in intelligent control theory, and evaluation of conventional and unconventional process variable sensors.

To achieve the desired performance objectives of high specific impulse and high thrust to weight ratios, nuclear rockets are designed to operate near the maximum solid core material temperatures. Therefore, the instantaneous temperature distribution in the core is a critical parameter for system safety and reliability, and the control system must have the ability to tightly regulate the core temperatures for all operating conditions. Unfortunately, with current sensor technology, it will be impossible to directly and accurately measure the core temperature distribution at the higher power levels.[3] Therefore, a method for system identification/parameter estimation must be included in the control system architecture for verification of the core temperature regulation.

The nuclear rocket control architecture must provide stability, robustness, and good tracking of the desired performance objectives (thrust and specific impulse), while maintaining constraints on system safety and reliability parameters such as instantaneous core temperatures and reactivity margins. In addition, the control architecture must provide for rapid identification of faults and adjustment of the actuator inputs to provide desirable performance without violating the system safety and reliability constraints.

An integrated control and health monitoring architecture that meets the above requirements is currently under development for the Pratt & Whitney nuclear rocket. As shown in Figure 1, the architecture is modular to allow for easier development and upgrades as new algorithms become available, and to permit implementation in a distributed manner. The modules consist of

1. a bank of preprogrammed controllers that have been preconfigured via simulation modeling or ground-based testing to provide desirable performance regulation for various different operation modes and conditions,
2. a signal validation module to provide analytic redundancy of the sensor and control signals to identify if a signal is indicative of a system component failure or of a sensor or signal processing failure,
3. a system identification module to estimate system safety and reliability parameters such as instantaneous and projected core temperature distribution,
4. a health monitoring /diagnostics module to identify the current health and operating conditions of the nuclear rocket (plant), and
5. the intelligent supervisory controller module which evaluates the performance of the system with the information from the system identification and health monitoring modules, and selects a controller from the bank of preprogrammed controllers that will provide the desired performance response without violating the system safety and reliability constraints.

The focus of our current work is to complete a dynamic simulation model of the nuclear rocket and to develop a bank of low level controllers to handle system startup, throttling to full power, shutdown, and several basic system faults such as turbopump or valve failures. A dynamic simulation system for modeling nuclear rockets is being developed using the *Simulink/Matlab* simulation and numerical analysis software. This simulation system consists of a series of modules that model basic physical phenomena such as 1-D compressible flow in a pipe, lumped parameter heat transfer, and point reactor kinetics. These modules can then be connected via the point and click *Simulink* user interface to build the nodes of a one dimensional model. These nodes are then copied, moved, and appropriately connected, again via point and click, to form higher level components of a nuclear rocket such as core regions, transfer pipes, and turbopumps. These components are then connected to build the complete system model. Current model development work consists of building more system components, including valves, tubopumps, and two-phase flow pipes, integrating multiple reactor kinetics modules to more accurately model the temperature reactivity feedbacks, and automating the initialization routines. The identification and configuration of the low level controllers to give desirable performance for the various operating modes and faulted conditions is being accomplished using modern control development techniques within the *Simulink/Matlab* environment.

There are currently several signal validation, system identification, and health monitoring algorithms available which should be adequate to test the control and health monitoring architecture.[4,5,6] Therefore, our future efforts will be in the development of the intelligent supervisory controller module. Artificial intelligence and knowledge processing will be key elements of the supervisory controller. There is substantial current work in these areas,[7,8] but much work remains in the development and application of this technology to nuclear thermal propulsive systems.

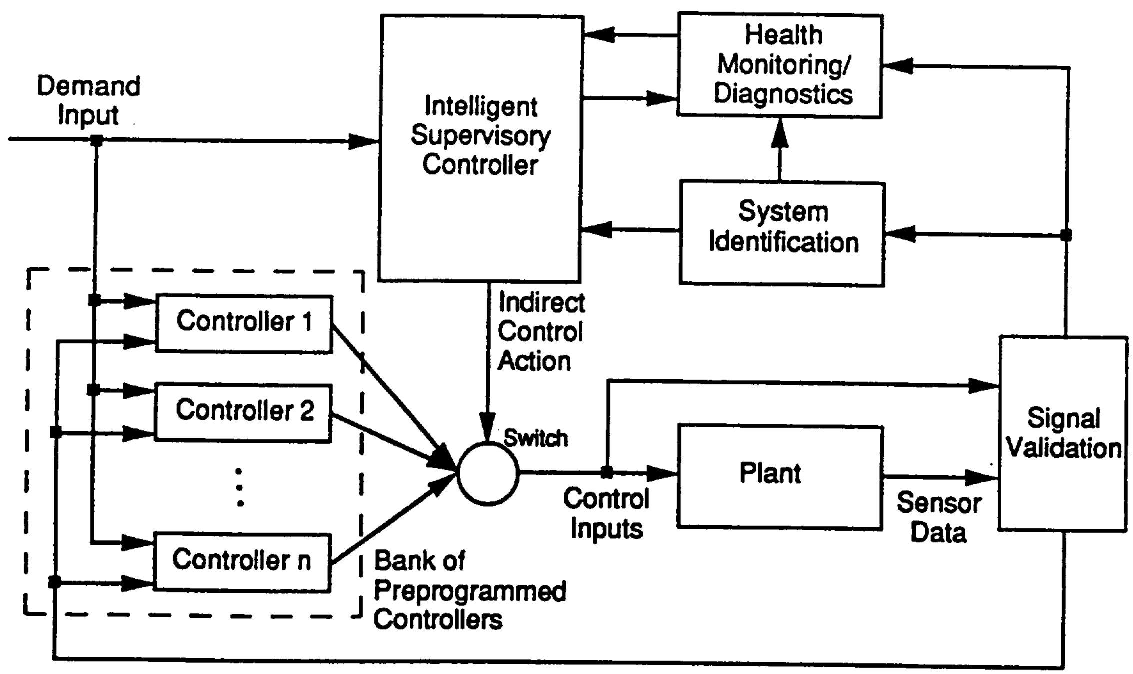

Figure 1: Integrated Control and Health Monitoring Architecture for Nuclear Rockets

Acknowledgments

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