Verification and Validation of Adaptive Control Systems

Modern exploration missions require modern control systems-control systems that can handle catastrophic changes in the system's behavior, compensate for slow deterioration in sustained operations, and support fast system ID. Adaptive controllers have these capabilities, but they can only be used safely if proper V&V can be done.

Background

Control systems are ubiquitous. Long duration or autonomous missions require that the control systems must be able to recognize and react to failures and changes in the dynamics of the systems which can not be addressed by traditional controllers. Spacecrafts and missions like CEV or JIMO pose substantial requirements on controllers as they do not perform in the same way than that they do during earth-based experiments. The individual systems (often nonlinear) must be controlled safely and reliably in environments where it is virtually impossible to analyze—ahead of time—all the important and possible scenarios and environmental factors, e.g., system components (e.g., gyros, bearings of reaction wheels, leaks) may deteriorate or break during long-lasting missions, leading to a sudden, drastic change in the plant's performance. Manual repair (in space) may not be an option in case of failure or component breakdown. Thus the system (autonomous or not) must be able to cope with equipment failure or deterioration. Controllability of the system must be re-established as fast as possible with a minimum of deactivation or shutdown of the system being controlled. Traditional fixed-gain controllers do not provide the required capabilities. Moreover, design of the control architecture, system identification, implementation, and verification and validation (V&V) are substantial cost drivers in safety critical systems.

These issues can be addressed by *intelligent, nonlinear adaptive controllers*. Here, machine learning algorithms (e.g., neural networks, reinforcement learning) can help as they can dynamically adapt toward the changes in the system. Theoretical background and design principles for such controllers has been developed to high maturity.

Research Overview

Due to the nonlinear and dynamic nature of an adaptive control system, traditional V&V and certification techniques are not sufficient for these adaptive controllers which a big barrier in their deployment in the safety-critical applications. Moreover, traditional methods of V&V involve testing under various conditions which is costly to run and requires a scheduling a long time in advance. We have developed specific techniques, tools, and processes to perform design time analysis, verification and validation, and for dynamic monitoring of such controllers. Combined with advanced modeling tools, an integrated development/deployment methodology for addressing complex control needs in a safety- and reliability-critical mission environment can be provided.

V&V of Adaptive Controllers

In order to fulfill the requirements for complex systems and missions like Prometheus or CEV, a unified approach for Verification and Validation for *design*, *analysis*, *implementation*, and *monitoring* of the system is necessary. Our approach uses a unique combination of methematically rigorous analysis (e.g., Lyapunov based methods) with intelligent testing and dynamic performance monitoring. Due to the adaptive nature, the performance of an adaptive controller needs to be monitored during the actual mission. Monitoring of the controller performance is vital for safe operation in unknown and possible changing environments. Only a dynamic measure can tell for sure if the controller (e.g., for reactor cooling) is still within the safety margin, even under unanticipated or un-modeled changes in the environment. A signal of low control performance can be used for early fault detection and analysis, potentially reducing the effort of in space maintenance without loss of safety and avoid catastrophic situations.

Logic-based approaches are combined with Bayesian statistical techniques for an on-line performance monitoring of the adaptive control system regarding speed and quality of adaptation and confidence of the output. Our Bayesian Confidence Tool provides a dynamic performance measure. It is integrated into an advanced flight computer of an F15-ACTIVE and will be test-flown later this year.

Relevance to Exploration Systems

CEV and

H&RT Program Elements:

This research capability supports the following H&RT program /elements:

ASTP/Software, Intelligent Systems & Modeling

ASTP/Advanced Materials and Structures

ASTP/Power and Propulsion

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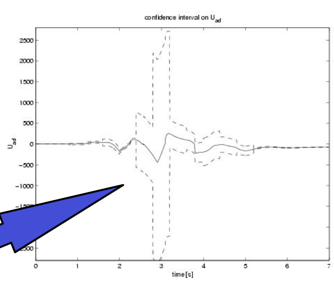

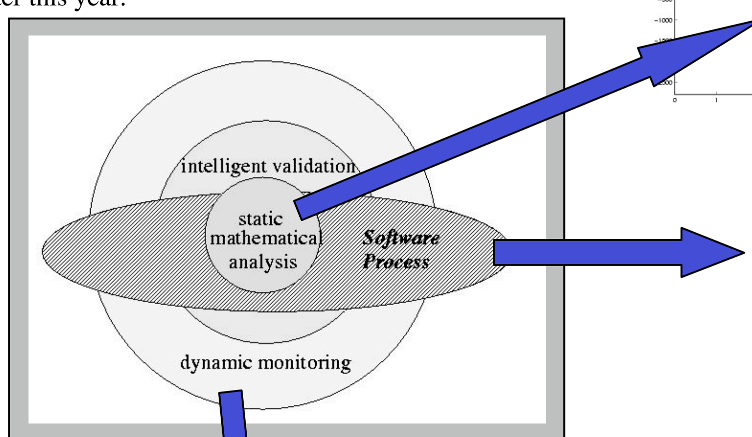

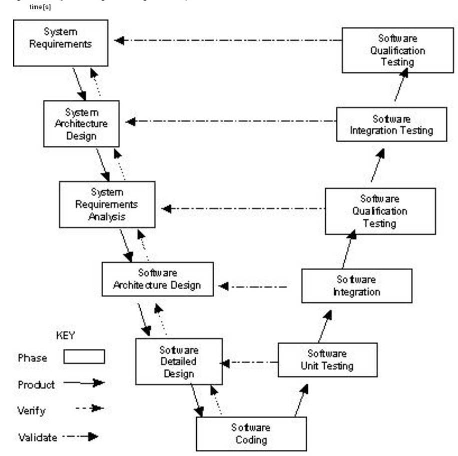

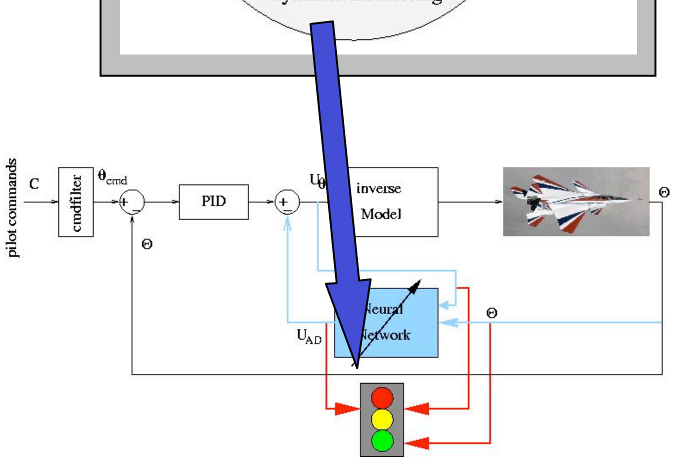

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