Verification and Validation of Adaptive Control Software

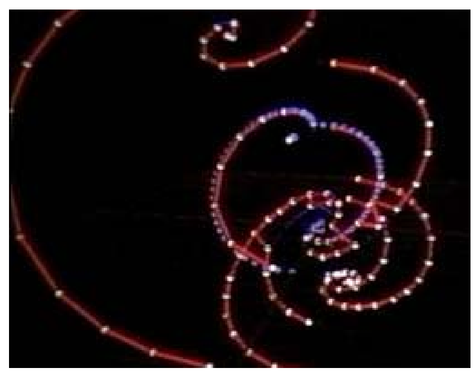
USRA's Research Institute for Advanced Computer Science (RIACS), in collaboration with the NASA Ames Research Center's Intelligent Systems Division and its partners, is developing advanced tools and techniques for the verification and validation of adaptive control software.

Adaptive control technology represents a significant leap forward in the development of machine control systems. Instead of simply controlling a system, adaptive controllers provide complex systems with the ability to compensate for a wide variety of system failures on the fly without having any prior knowledge of how the system has failed. For example, a flight control computer for an aircraft takes input from the pilot via the control stick and uses this information to adjust the craft's flight control surfaces accordingly, causing it to go up, down, left, or right, as the pilot requests. An adaptive flight controller can do the same thing but with one significant exception: In the event that one of the control surfaces on the aircraft were to fail, the adaptive controller would be able to use the remaining flight control surfaces on the aircraft to compensate for the failed component.

Since aircraft are safety-critical systems, it is vital that the flight controllers used to control them be reliable and certified. Prior to being flight certified, they must go through a rigorous verification and validation process. This process subjects the flight control system to a wide variety of tests to ensure that it will function properly under both nominal and failure conditions, even in unforeseen circumstances.

V&V at a Glance

- Works with a variety of adaptive control architectures, such as sliding mode control, fuzzy logic, and most types of neural networks
- Takes a unified approach to support verification and validation for design, analysis, implementation, and monitoring of adaptive controllers
- Based on strong mathematical and statistical principles, using a mathematical description of the problem, and does not require any simplifying assumptions
- Tested as part of the NASA Intelligent Flight Control System (IFCS) during manned flight tests on a NASA F-15 aircraft
- Versions available in both Matlab and C



Neural-network–based adaptive controllers represent the future of control software.

Due to an adaptive flight controller's ability to evolve over time, it is not possible to validate its dynamic capabilities using traditional verification and validation methods. Whereas these traditional methods are used to make sure that all systems are functioning properly under nominal or known conditions, verification and validation of an adaptive controller must ensure that the controller is operating safely under all operating conditions.

RIACS researchers have developed a suite of advanced tools, techniques and software processes to ensure that adaptive controllers meet their specifications and operate correctly. These approaches use a unique combination of mathematically rigorous analysis with intelligent testing and dynamic performance monitoring. Advanced Bayesian statistical techniques are the basis for real-time performance monitoring of adaptive systems. The monitoring tools can provide dynamic performance measurements with respect to the quality of the controller's adaptation as well as the confidence of the output it produces.

It is important to note that this approach to verification and validation is not limited only to in-flight monitoring. These tools, techniques, and processes together provide a unified method of verification and validation for design, analysis, implementation, and monitoring.

Broad Applicability

The verification and validation methods and technologies being developed for adaptive controllers can be utilized in a wide variety of applications and a broad set of control technologies. While in the case of the Intelligent Flight Control Systems (IFCS) project, these techniques are applied to a neural-network–based adaptive controller, they can also be utilized on other control architectures like sliding mode control systems and fuzzy control systems, among others. As a result, many different types of spacecraft and machines that employ adaptive controllers can leverage these verification and validation methodologies.

NASA's Crew Exploration Vehicle (CEV)—as well as countless other satellites, robotic explorers, and spacecraft—can all benefit from this technology. Earthbound applications include military aircraft and equipment, commercial aircraft, chemical and power plants, and any machines with complex, non-linear adaptive control systems.

Put to the Test

As part of the NASA/Boeing/ISR Intelligent Flight Control Systems project, verification and validation technologies for adaptive controllers (at TRL 7) were put to the test this past winter in Southern California. The dynamic monitoring tool has been implemented on the flight hardware of a modified F-15 and was subjected to manned flight tests.

During these flights, control surface failures were simulated, with the monitoring software recording and analyzing flight performance in real time. This in-flight monitoring of an adaptive controller is vital to ensure safe operation in unknown and possibly changing environments.

Supporting NASA's Exploration Vision

The verification and validation tools, techniques, and processes being developed by RIACS will provide direct benefit to NASA in helping the Agency achieve its Vision for Space Exploration. Adaptive control technology will be important for the future Crew Exploration Vehicle as well as other advanced spacecraft and robotic exploration systems. Verification and validation technologies will help ensure that these systems operate safely and reliably.

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