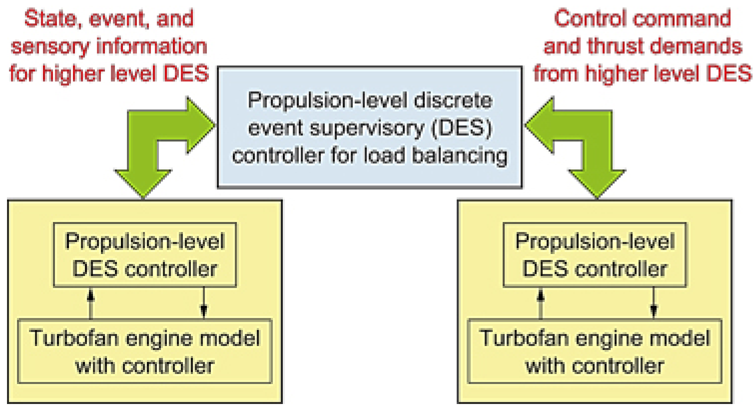
Discrete Event Supervisory Control Applied to Propulsion Systems

The theory of discrete event supervisory (DES) control was applied to the optimal control of a twin-engine aircraft propulsion system and demonstrated in a simulation. The supervisory control, which is implemented as a finite-state automaton, oversees the behavior of a system and manages it in such a way that it maximizes a performance criterion, similar to a traditional optimal control problem. DES controllers can be nested such that a high-level controller supervises multiple lower level controllers. This structure can be expanded to control huge, complex systems, providing optimal performance and increasing autonomy with each additional level.

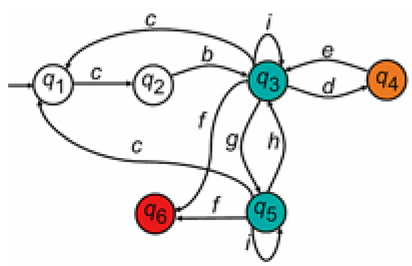
The DES control strategy for propulsion systems was validated using a distributed testbed consisting of multiple computers--each representing a module of the overall propulsion system--to simulate real-time hardware-in-the-loop testing. In the first experiment, DES control was applied to the operation of a nonlinear simulation of a turbofan engine (running in closed loop using its own feedback controller) to minimize engine structural damage caused by a combination of thermal and structural loads. This enables increased on-wing time for the engine through better management of the engine-component life usage. Thus, the engine-level DES acts as a life-extending controller through its interaction with and manipulation of the engine's operation.

Next, the DES control strategy was applied to a simulation of a twin engine aircraft's propulsion control system, where each of the engines had its own low-level DES controller as in the first experiment. This higher level propulsion control specifically addressed the issue of load balancing between the engines to maintain overall propulsion performance. The propulsion-level DES achieved this by giving the engine that could better handle the load the majority of the burden and giving the engine with more accumulated component damage (less remaining component life) the smaller share of the load. The simulation runs demonstrated that the system with the propulsion-level DES control was able to successfully complete the predefined mission more consistently than the system without the controller.



Twin-engine aircraft propulsion system showing the hierarchical propulsion-level DES controller above the two engine-level DES controllers.

The experiments demonstrated that hierarchical discrete-event supervisory control could successfully manage the operation of a complex system in an intelligent manner to achieve the goals of the mission. They also demonstrated that as more levels of DES control are implemented, the level of autonomy of the overall system increases. Researchers at the NASA Glenn Research Center have been working with grantees at the Pennsylvania State University to more fully develop the hierarchical DES theory for application to aerospace-related problems.



The engine-level DES is a finite-state machine representing the set of states (circles) and events (arrows) that model the operation of the engine.

Long description of figure. This finite-state automaton depicts the engine-level DES controller. It is made up of a set of circles, signifying states, partially connected by arrows, signifying events. In this example, the state of the engine represents the engine's operating status. Each modeled event triggers a transition from one state to another, and it may be caused by an external input or from the DES.

Bibliography

Fu, Jinbo; Yasar, Murat; and Ray, Asok: Optimal Discrete Event Supervisory Control of Aircraft Gas Turbine Engines. Proceedings of the American Control Conference, Boston, MA, June 2004.

Yasar, M., et al.: Hierarchical Discrete Event Supervisory Control of Aircraft Propulsion Systems. AIAA–2004–6469, 2004.

U.S. Army Research Laboratory, Vehicle Technology Directorate at Glenn contact:
Jonathan S. Litt, 216–433–3748, Jonathan.S.Litt@grc.nasa.gov
Glenn contact: Neerav Shah, 216–433–3502, Neerav.Shah@nasa.gov
Authors: Jonathan S. Litt and Neerav Shah
Headquarters program office: Aeronautics Research
Programs/Projects: Engineering for Complex Systems