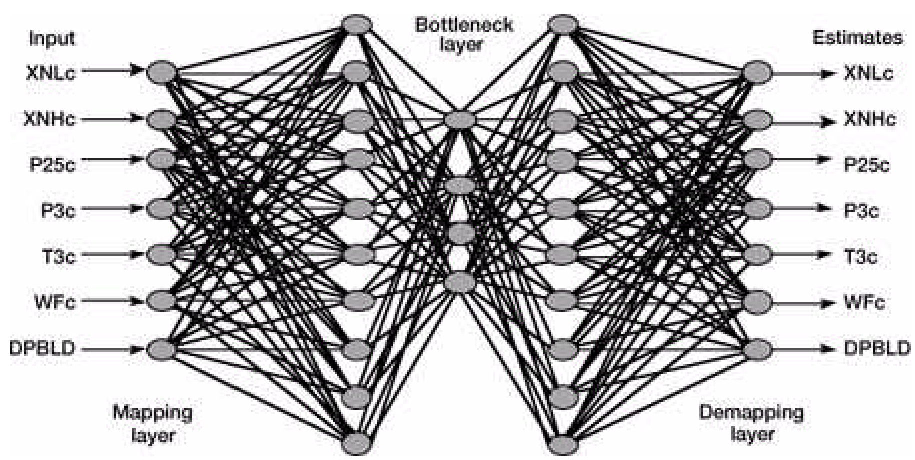
High Reliability Engine Control Demonstrated for Aircraft Engines

For a dual redundant-control system, which is typical for short-haul aircraft, if a failure is detected in a control sensor, the engine control is transferred to a safety mode and an advisory is issued for immediate maintenance action to replace the failed sensor. The safety mode typically results in severely degraded engine performance. The goal of the High Reliability Engine Control (HREC) program was to demonstrate that the neural-network-based sensor validation technology can safely operate an engine by using the nominal closed-loop control during and after sensor failures. With this technology, engine performance could be maintained, and the sensor could be replaced as a conveniently scheduled maintenance action.

The neural network architecture used here for the sensor validation is the Auto-Associative Neural Network (AANN). This feed-forward network architecture has output data that reproduce the network input data (see the following figure). AANN consists of two layers, the mapping layer and the demapping layer, which are interconnected through the bottleneck layer. The mapping layer compresses the data into a reduced-order representation, eliminating redundancies and extracting the key features (principal components) in the data. Reducing the number of dimensions is the key characteristic of this architecture. The demapping layer recovers the encoded information from the principal components. In addition, a fault detection logic identifies the unique sensor failure based on the pattern of the error vector of the input and output of the AANN.

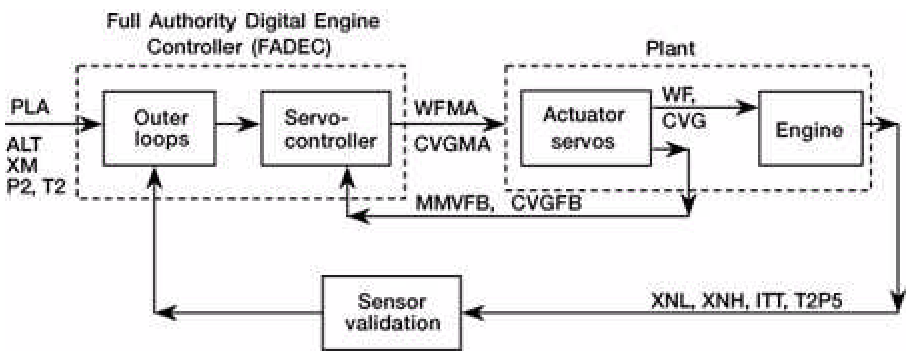


Auto-associative neural network schematic (7-10-4-10-7 network) for turbofan engine estimates.

Variable	Engine parameter

DPBLD	Delta pressure between compressor discharge and bypass duct
P25	Low-pressure compressor inlet pressure
P3	Compressor discharge pressure, burner inlet
T3	Temperature at burner inlet
WF	Fuel flow
XNL	Fan rotor speed
XNH	Core rotor speed

In March 1998 the High Reliability Engine Control program successfully demonstrated the neural-network-based sensor failure detection and accommodation algorithm on a real-time simulation of the Allison's AE3007 engine and its Full Authority Digital Engine Controller (FADEC, ref. 1). Successful accommodation of faults for low- and high-speed rotor speed sensors was demonstrated in the closed-loop engine simulation (see the following flow diagram).



Closed-loop control with sensor validation.

Variable	Engine parameter
ALT	Aircraft altitude
CVGMA	Compressor variable geometry command
CVGFB	Compressor variable geometry feedback
ITT	Interstage turbine temperature

MMVFB	Main metering valve feedback signal
PLA	Power lever angle (thrust command)
P2	Fan inlet pressure
T2	Fan inlet temperature
T2P5	Compressor inlet temperature
WFMA	Main metering valve command
XM	Aircraft Mach number
XNL	Fan rotor speed
XNH	Core rotor speed

Simulation results show that the neural-network-based sensor validation algorithm can identify both hard and soft sensor failures and can estimate how long the engine control will operate without degradation (ref. 2).

The High Reliability Engine Control program is a collaborative effort between NASA, the Allison Engine Company, and Scientific Monitoring Inc., a small business. In this program, NASA provided the sensor failure detection technology which included the neural network modeling, training, and detection algorithm. Allison Engine Company provided the expertise in AE3007 engine model and control, and Scientific Monitoring Inc. did the system integration and implementation. This program gave these research collaborators an opportunity to further develop and transfer NASA-developed advanced technology for sensor failure detection, isolation, and accommodation to aircraft engine industry.

References

1. Mattern, D.L., et al.: Using Neural Networks for Sensor Validation. AIAA Paper 98-3547, 1998.

2. Allison Engine Co**.:** AE 3007 High Reliability Engine Control Program. Development/Demonstration of Reliability Enhanced Control Technologies to Improve Aircraft Dispatch Reliability. NASA3-27394, Task Order 008, EDR 18549, Final Contractor Report, April 1998.

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