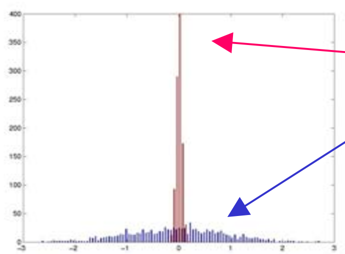
Information Sciences & Technology

Ames Research Center

Confidence Tool for Neuro-Adaptive Controllers

Catastrophic changes can be handled by Neuro-adaptive controllers: neural networks are trained *during flight.* Important for V&V:

How good is the network performing at the moment?

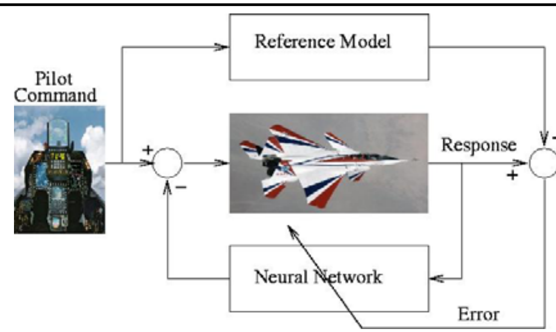


Our approach: The Confidence Tool analyzes the probability density of the neural network output and produces error bars:

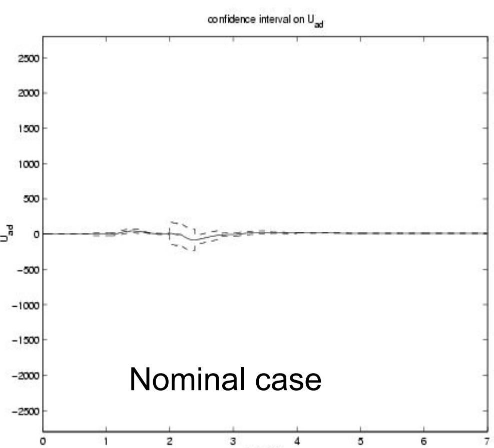
•Small variance = small error bar = good, reliable estimate

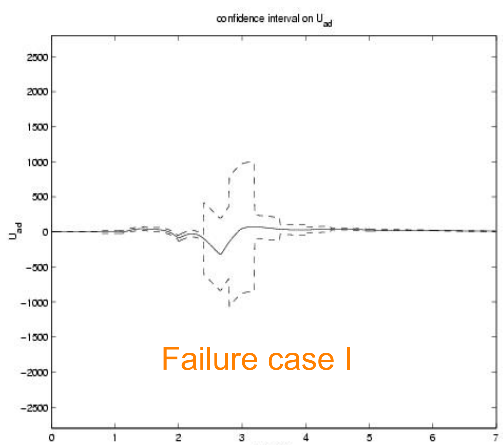
•Large variance = large error bar = bad performance

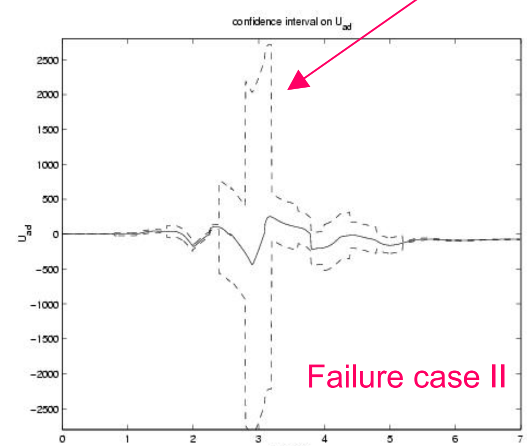
Confidence tool integrated into IFCS Gen-II Simulink Model



Severe failure: large error bar over extended period of time







Confidence Tool

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- **Background:** Software for safety-critical tasks (e.g., aircraft control) must undergo rigorous verification and validation (V&V) before it can be deployed. The primary motivation of this work is to enable the use of neural networks (NN) in safety-critical control applications. The aerospace industry has perceived neural networks as inherently unpredictable, and therefore difficult to certify. This opinion is partly due to misunderstandings surrounding the issue of off-line and on-line training. The goal of the work is develop techniques and tools for rigorous V&V of NN based adaptive controllers ultimately supporting their certification – a major prerequisite for most NASA applications. Such adaptive controllers are currently implemented and tested at NASA Dryden on F-15 and C-17. Our approach combines mathematical analysis with dynamic monitoring to ensure robust convergence and stability. We have implemented a prototypical tool, using a Bayesian approach to analyze the (Gaussian) probability distribution of the neural network output. The variance of the output, σ, dynamically calculates the confidence measure which is depicted as error bars around the output of the network. This metric describes the quality of the NN performance. Small variances, depicted as small error-bars indicate a good estimate, and thus high confidence in the neural network performance. Our confidence tool (implemented in Simulink/Matlab and C) can be used for pre-deployment verification, and, as a prototype software harness to monitor quality of adaptation during the mission. This tool can be used for pre-trained neural networks (IFCS Gen-I) as well as for neural networks which adapt during the flight (on-line adaptive NN, IFCS Gen-II).
- **Shown:** Graphs show the confidence interval (error bars) around the actual output of the neural network during a simulation run for nominal and failure cases. The Simulink model for the IFCS Gen-II architecture has been provided by DFRC. At t=2s, a pilot action starts. Even in the nominal case, the on-line adaptive neural network produces some output to counter-act small modeling errors. The small error bar indicates high confidence in the NN's behavior. In failure case I (stabilizer failure), a substantial NN output is required to keep the aircraft controllable. Here, the error bars are momentarily large, indicating that the network has to adapt to the changed aerodynamics. Failure case II simulates a severe failure. Here, the system needs substantial time (and various fluctuations) to converge. In this case, the error bar gets very large for an extended period of time.
- **Accomplishment:** This work and the confidence tool prototype was presented at NASA Dryden (DFRC) on 07/09-07/10/2003 during PDR and TQM of IFCS project. The tool was successfully demonstrated during the meeting.
- **Future Plans:** Future plans include the integration of the confidence tool into the control-room and to perform tests during actual test flights. It is also intended to integrate this tool into the Hardware in the Loop simulator for F-15 at Dryden. Boeing has shown substantial interest in using our tools for their projects. Additional activities include work on a Software V&V process guide for NN based controllers.