Performance Monitoring and Assessment of Neuro-Adaptive Controllers for Aerospace Applications Using a Bayesian Approach

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Modern aircraft, UAVs, and robotic spacecraft pose substantial requirements on controllers in the light of ever increasing demands for reusability, affordability, and reliability. The individual systems (which are 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. For example, system components (e.g., gyros, bearings of reaction wheels, valves) may deteriorate or break during autonomous UAV operation or long-lasting space missions, leading to a sudden, drastic change in vehicle performance. Manual repair or replacement is not an option in such cases. Instead, the system must be able to cope with equipment failure and deterioration. Controllability of the system must be retained as good as possible or re-established as fast as possible with a minimum of deactivation or shutdown of the system being controlled. In such situations the control engineer has to employ adaptive control systems that automatically sense and correct themselves whenever drastic disturbances and/or severe changes in the plant or environment occur.

Over the recent years, artificial neural networks (NN) have found their way into various safety-related and safety-critical areas, like transportation, avionics, environmental monitoring and control, and medical applications. Although many of these applications have proved to be highly successful, they also pose high risks and significant development costs, producing certain reluctance to adopting these new and sometimes complex and difficult-to-understand technologies. Of chief concern is the general question of how can it be guaranteed that the NN-based adaptive control system performs as expected in all. While theory and concepts of adaptive systems and intelligent control have been studied in depth over the past decade or so, only very little attention has been paid to the issue of validating the correctness and safety of their operation and monitoring their performance during operation.

Validating the correct performance of a controller requires a set of concise design requirements and performance criteria. In the case of control systems for piloted aircraft, generally applicable quantitative design criteria are very difficult to obtain. The reason for this is that the ultimate evaluation of a human-operator control system is necessarily subjective and, with aircraft, the pilot evaluates the aircraft in different ways depending on the type of aircraft and phase of flight. In most aerospace applications (e.g., for flight control systems), performance assessment is carried out in terms of handling qualities. Handling qualities may be defined as those dynamic and static properties of a vehicle that permit the pilot to fully exploit its performance and other potential in a variety of missions and roles. Traditionally, handling quality is measured using the Cooper-Harper rating done subjectively by human pilots for aircraft control. In our study, which will be described in this paper, we use a quantitative approach using low order equivalent system (LOES) model of the aircraft. The LOES approach is to match the high order responses with the low order responses of the familiar modes. LOES allows specification of model dynamics consisting of low order systems with preferred values of damping, frequency or time constant. A central element for assessing the performance of a neuro-adaptive controller is the ability to dynamically monitor the performance of the adaptive neural network.

We have developed a set of related tools, which can be used in all phases of the software lifecycle (including system design, simulation, system prototype development, deployment, and in-operation monitoring) to assess the performance of neural controllers *while in-flight.* These tools (confidence tool, envelope tool) are based on Bayesian methods and are capable produce statistical confidence intervals for the controller signals. Using this knowledge of the error and of the network or model, our tools will allow real-time assessment of vehicle performance and provide an estimate of important handling quality characteristics.

In this paper we will present the methods of measuring the performance of a neuro-adaptive controller and how the tool performance metric relates to the control system robustness and the vehicle handling characteristics. Simulation results will be presented and tool design concepts will be explained in the context of NASA's Intelligent Flight Control System (IFCS) project being conducted by NASA at the Dryden Flight Research Center on a specially modified F-15 research test bed aircraft. The aim of this study is to conduct adaptive flight control work and to develop software tools and techniques for the verification and validation of neural network controlled aircraft. In this research program, a controller with adaptive neural networks is used to compensate for control errors in aircraft dynamics caused by damaged or failed aircraft control surfaces. The handling qualities information that is generated by the confidence and envelop tools is passed though an interface to the deliberative or reactive flight control planner. For the IFCS aircraft, the planner element is the pilot. However, this quantitative information on the handling qualities can also be used by higher-level decision processes in autonomous systems as well. The treatment of this statistical information on handling qualities and how it relates to controllability, safety margins, the current status of the adaptation process will be explained in the paper.