JOURNAL OF GUIDANCE, CONTROL, AND DYNAMICS
Vol. 15, No. 2, March-April 1992

Fault Diagnosis for the Space Shuttle Main Engine

Ahmet Duyar*
Florida Atlantic University, Boca Raton, Florida 33431
and
Walter Merrill†
NASA Lewis Research Center, Cleveland, Ohio 44135

A conceptual design of a model-based fault detection and diagnosis system is developed for the Space Shuttle main engine. The design approach consists of process modeling, residual generation, and fault detection and diagnosis. The engine is modeled using a discrete time, quasilinear state-space representation. Model parameters are determined by identification. Residuals generated from the model are used by a neural network to detect and diagnose engine component faults. Fault diagnosis is accomplished by training the neural network to recognize the pattern of the respective fault signatures. Preliminary results for a failed valve, generated using a full, nonlinear simulation of the engine, are presented. These results indicate that the developed approach can be used for fault detection and diagnosis. The results also show that the developed model is an accurate and reliable predictor of the highly nonlinear and very complex engine.

Introduction

THIS paper describes a model-based fault diagnosis system based on a neural network classifier for the Space Shuttle main engine (SSME). The system may be used to monitor the life cycle of engine components and for the early detection, isolation, and the diagnosis of engine faults. As such, the proposed system will be one part of a larger, engine health monitoring system.[1] The health monitoring system will allow for accommodation of faults, reduce maintenance cost, increase engine availability, and be one part of an integrated, intelligent control system[2] for the SSME. A description of SSME dynamics and its modeling is given in a study by Duyar et al.[3] A summary of the major failures of the SSME that have occurred are outlined by Cikanek.[4] Several authors[5-8] survey the available methods and approaches for fault detection and diagnosis. In particular, the survey by Isermann[6] gives several examples of the use of identification techniques for process fault detection.

A fault is the abnormal behavior of a component due to physical change in the component. A fault event often impairs or deteriorates the system's ability to perform its specified tasks or mission. The detection task is defined as the act of identifying the presence of an unspecified fault. After a fault is detected, then the fault must be isolated to the component that has failed. During the process of isolation, the magnitude of the fault may be estimated. Fault diagnosis is the isolation and estimation of a fault mode. Once a fault is detected and diagnosed, the fault can be accommodated through reconfiguration of the system. Reconfiguration includes both hardware actions (e.g., activating backup systems) and software tasks (e.g., adjusting the feedback control gains). The detection and diagnostic tasks may be accomplished by an onboard processor, on line and in real time for fault accommodation, as well as by an off-line processor that analyzes recorded data for life-cycle analysis and preventive maintenance.

Received July 7, 1990; revision received Oct. 26, 1990; accepted for publication Feb. 21, 1991.

*Professor, Mechanical Engineering Department.

†Deputy Branch Chief, Advanced Controls Technology Branch, Mail Stop 77-1, 21000 Brookpark Road. Senior Member AIAA.

Initially, a brief description of the conceptual design of the model-based fault detection and diagnostic system (FDDS) is given. This is followed by a description of the process modeling, the residual generation method, and the detection and diagnostic system design. Finally, results of the application of the FDDS to the detection of a stuck valve fault using simulated data are presented.

Conceptual Design

Model-based fault detection methods rely on the determination of changes appearing in the system due to the existence of a fault, in comparison with the normal status of the system. For example, in aerospace applications control actuator faults may be represented as shifts in the parameters of the control gain matrix. Sensor faults may be represented as abrupt changes in the parameters of the output matrix or increases in measurement noise. These changes are determined by comparing the parameters of the observed process with the parameters obtained from the model of the normal process. The differences between these parameters are called residuals. The residuals and their patterns are analyzed for fault detection and diagnosis by comparing them with the known fault signatures of the process.

Fault signatures, which show the effect of a fault on the parameters, are generated by inducing faults in the nonlinear dynamic simulation of the process. Fault diagnosis is accomplished by training a neural network classifier to recognize the pattern of the respective fault signatures.

The design of the FDDS is accomplished in three stages: process modeling, residual generation and fault detection, and diagnostic classifier design. In the following sections the methods used in these stages are briefly explained.

Process Modeling

A complete nonlinear dynamic simulation of SSME performance was developed by Rocketdyne Division of Rockwell International Corporation.[9] In this study, this nonlinear model is considered as the unknown process. It is used for the generation of fault signatures by modifying the actuator models to include a fault model. The input-output data generated from this simulation are also used to identify the parameters of the engine. Due to its size and complexity (40 min of CPU time for 20 s of real-time operation with a VAX 8800), this nonlinear simulation cannot be used to generate data in real time to describe the normal mode of operation.