Using Information Theory in Optimal Test Point Selection for Health Management in NASA's Exploration Vehicles

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This abstract describes the objectives and contributions of the paper (to be submitted in full to WCSMO-2005) as well as our status and plans for this ongoing research.

~~*Keywords: Sensor Placement Optimization, Design for Testability, Reusable Launch Vehicles*~~

1. Overview

Background: Over the past few years, NASA in collaboration with other governmental and private research entities has initiated projects to develop a new generation of exploration vehicles -- referred to as Reusable Launch Vehicles. RLV's can conduct multiple missions and are expected to replace space shuttle systems and expandable launch vehicles. Due to the complexity of such vehicles, ensuring the reliability and safety of a mission has become a formidable task. Therefore, the Discovery and Systems Health group (DaSH) in the NASA Ames Research Center is developing Integrated Health Monitoring (IHM) systems to cover areas of potential failure in RLV's and other similar complex space systems.

Test Point Selection Problem: An ongoing research in NASA has resulted in a series of modules to quantify the impact of IHM on factors such as safety, operations, reliability, false alarm rate, and testability of a given RLV design. One of the main goals of this research is to identify test points where instruments can be deployed to provide maximum fault coverage and isolation ability. Given the fact that such instruments (sensors) are susceptible to failure themselves or may provide faulty measurements under certain conditions, test point selection

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problem has become the subject of intense research in many other applications. In this paper, a sensor placement optimization problem is defined that maximizes the expected value of the information obtained by IHM systems.

2. Objectives and Contributions

In this paper, we will present a new methodology that measures the "worth" of deploying an additional testing instrument (sensor) in terms of the amount of information that can be retrieved from such measurement. This quantity is obtained using a probabilistic model of RLV's that has been partially developed in the NASA Ames Research Center[2]. A number of correlated attributes are identified and used to obtain the worth of deploying a sensor in a given test point from an information-theoretic viewpoint.

Once the information-theoretic worth of sensors is formulated and incorporated into our general model for IHM performance, the problem can be formulated as a constrained optimization problem where reliability and operational safety of the system as a whole is considered. Although this research is conducted specifically for RLV's, the proposed methodology in its generic form can be easily extended to other domains of systems health monitoring.

3. Status and Plans

The modular simulation of IHM impact on RLV safety is available at NASA. Currently, we are working to integrate these modules into an overall framework that can be used to optimize the deployment of measurement instruments, as suggested in this research. A generic Two-Stage-To-Orbit (TSTO) RLV design example is used to demonstrate our new methodology.

[2] K. Datta, N. Jize, D. Maclise, D. Goggin, 2003, "An IVHM Systems Analysis & Optimization Process", IEEEAC paper #1094.