Verification and Validation of System Health Management Models using Parametric Testing

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Abstract

Integrated Vehicle Health Management (IVHM) systems have found their way into many safety-critical aerospace and industrial applications. Most major components of aircraft (e.g., jet engines, hydraulics, or electric power systems) are monitored by an IVHM system. An IVHM system processes readings from sensors throughout the system and uses a Health Management (HM) model to detect and identify faults (diagnosis) and to predict failures in the near future (prognosis).

It is obvious that an IVHM system, which monitors a safety-critical component, must be at least as reliable and safe as the component itself—false alarms or missed adverse events are not acceptable. Therefore, the IVHM system, a piece of software, must undergo rigorous V&V on model and implementation level.

In this paper, we will describe an advanced technique for the analysis and V&V of Health Management models. For our studies, we use Health Management systems that are modeled using Bayesian Networks (BN). BNs are a powerful modeling paradigm to express notions of cause and effect, probability, and reliability. Such networks may also be compiled into clique trees or arithmetic circuits for efficient (embedded) execution. Arithmetic circuits push much of the work involved in performing inference to an offline phase, which can then be amortized across many online queries.

A Bayesian model of a vehicle subsystem typically contains many parameters (e.g., thresholds for discretization or node probability values), which must be set carefully for reliable and correct HM reasoning. In this paper, we are investigating the use of Parametric Testing (PT), which uses a combination of n-factor and Monte Carlo methods to exercise our Bayesian HM model with variations of perturbed parameters. This technique avoids the excessive numbers of cases caused by combinatorial exploration while at the same time yielding good coverage of the parameter space. An n-factor of 3 is used in our experiments, which guarantees that all errors involving the specific setting of three or fewer parameters will be exercised by at least one test.

The result of model analysis with PT is a large, high-dimensional data set, which can be investigated using multivariate clustering to automatically find structure in the data set and to support visualization. PT yields valuable insights on the sensitivity of parameters (in our experiments: threshold parameters) and helps to detect safety margins and boundaries.

As a case study for this report we use HM models from the NASA ADAPT testbed, which is a realistic hardware setup for a distributed power system as found in spacecraft or aircraft. In our experiments, we perform multivariate clustering by means of the AutoBayes tool. Although the results described in this report are based upon ADAPT HM models, our analysis and V&V approach can be carried over to other applications and other HM modeling paradigms (e.g., table or rule-based systems).

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