Visitor Research Report

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Area of Research: **System Theory and Formal Methods**

Period of Visit: **October 17, 2007 through March 31, 2008**

Goal: Development of Theoretical Tools for the Formal Verification of Hybrid Jump Linear Systems

The goal of the proposed research was to develop a suit of methods to convert hybrid models into discrete models suitable for formal verification. This work was done in the framework of NASA's Internal Vehicle Health Management (IVHM) program.

A hybrid model is one that is composed of both continuous (uncountable) and finite dynamics evolving in discrete time. A typical example is a digital room temperature control. These models are of interest because they can be used to analyze fault tolerant technologies implemented in new commercial airplanes. NASA's interest, however, lies on the formal verification of such technologies. Hence the need to develop formal verification tools for hybrid systems of the aforementioned type.

As can be shown by the existing literature only finite dynamical systems or very simple hybrid systems can be routinely verified with the currently available computational and theoretical tools. The proposed research aimed to identify and extend some of these tools.

Strategy:
The work was divided in three stages.

1) Development of a practical example. The aim of this stage is to identify a practical example based on IVHM technology suitable for modeling and formal verification.

2) Development of the example's mathematical models. The aim of this stage is to develop the simplest possible mathematical model that represents the behavior the identified example. The model should be based on hybrid systems and be suitable for formal verification.

3) Formal verification of the example's mathematical model. The aim of this stage is to formally verify the properties of the example's model using model checker or PVS.

Accomplishments:

An important area of interest is the detection of faults (such as cracks) on airframe structures. NASA LaRC is developing a new technology for crack detection on wings based on Bragg fiber optics strain sensor. The detector acquires wing vibration data using a distributed set of sensors. The data is then processed to extract a specific set of indicators which are then compared to the theoretically predicted ones. The discrepancies are then used to identify specific faults in the wings.

Aircraft wing are usually modeled as cantilever beams. Consequently, a suitable cantilever vibration model was developed for both a pristine and a cracked cantilever. The model is sensitive to crack size and location, to changes in the physical parameters of the beam, and to changes in the loads acting on the cantilever.

A fault detection methodology was also developed. It is based on acquiring strain data in several points along the wing's main axis while the wing is driven by a periodic load. The data is then processed to obtain the shape the wing takes while vibrating. The latter is then mathematically compared against the theoretical shape the wing should have while vibrating. Both the cantilever model and the detection methodology are compatible with the Bragg fiber optics technology. They are also suitable for formal verification.

Since a complete prototype of a wing equipped with Bragg fiber optic sensors is not currently available, a Matlab-based simulation tool was also developed to test the detection methodology. The simulation tool generates the data the Bragg fiber optics sensors should produce when either a pristine wing or a crack wing is vibrating. The tool also allows the data to be processed by the detection algorithm. Early simulations have shown that the detection methodology is sound, although somehow difficult to implement.

In summary, stages 1 and 2 of the proposed research were completed.

Future Work:
There are several areas than need to be researched.

1) The cantilever model only permits permanently open crack. A more accurate model that allows for "breathing crack" (those that open and close with the wing vibration) need to be developed.

2) The basic physical assumptions of the model need to be contrasted against physical experiments.

3) Some basic properties of the model need to be formally verified in PVS.

4) The detection algorithm needs to be verified in PVS.

5) The third stage of the proposed research needs to be completed.

Pending Publications:

A full length report for NASA is currently under development. It should be published later this year (2008).

Seminar Presented:

This research was presented before NASA LaRC's and NIA's formal method groups on March 4th, 2008. The presentation is titled "Basic Fault Detection in Cantilever Beams" and is available upon request (atejadaru@gmail.com).