Automated Trend Analysis For Spacecraft System

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Abstract

The Automated Multimodal Trend Analysis System (AMTAS) developed at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center is designed to monitor, diagnose, and resolve spacecraft health and safety trends. It consists of a state estimator and predictor, and a Discrete Event Reasoner. The estimator and predictor dynamically model a set of telemetry data, and predict their future trends. The DER consists of a hypothesis generator and resolver, and a simulator. The diagnostic algorithm is model-based guided by an uncertainty handler. In this talk we discus a new development: an on-board Attitude Sensor Calibration (ASCAL), based on components developed for AMTAS. We will focus on its hybrid system structure.

Introduction

AMTAS's main objective is to perform intermediate (single orbit) and long term (multiple orbits) monitoring, diagnosis, and resolving spacecraft health and safety trends. It consists of two components: a state estimator and predictor, and Discrete Event Reasoner (DER). The estimator and predictor dynamically model a selected set of telemetry data, and predict their future trends. On the discrete side, the DER consists of a hypothesis generator and resolver, and a simulator. The diagnostic algorithm is model-based guided by an uncertainty handler [1,2] based on a modification of the Dempster-Shafer theory [3,4]. The uncertainty handler is designed to handle multiple fault problems. It is capable of updating its knowledgebase based on the system's past experiences. The knowledgebase has a control parameter that allows some flexibility for knowledgebase updating when an attempt to solve a problem fails.

The current prototype of AMTAS assumes that the system can be accurately represented by a static model in the sense that, the discrete states do not change during each diagnostic period. This is sufficiently accurate for most simple health and safety monitoring tasks. As a result, AMTAS is limited to operate as a ground system, relying only on available telemetry data. The ability to request additional measurements, which are crucial for fault isolation, is beyond AMTAS autonomous loop. User interface is needed to allow flight dynamics specialists to manually perform more extensive fault isolation to resolve difficult anomalies.

Our goal is to resolve this drawback and to improve the level of autonomy of AMTAS enough to operate on-board spacecraft. To achieve this goal, the uncertainty handler has to be modified to cope with temporal relations of events and multiple model situations. Moreover, in order to operate on-board spacecraft and interface with operational flight software, the estimator and predictor models must be dynamic.

Generally, flight software is a simple close loop control with little decision making capability. It performs necessary computation and sends out specific command directly to spacecraft. The plan is to integrate the predictor component with appropriate flight software, with an interface to the DER. The DER will perform higher level tasks such as diagnosis, planning, coordinating and scheduling. The heart of the diagnosis remains heuristic, based on an enhancement of the uncertainty handler designed for AMTAS. The approach we take is goal oriented, i.e. the integrated system is designed to autonomously perform a specific task. The first application we consider is the attitude sensor calibration task.

ASCAL

In a conventional spacecraft, the attitude is constantly computed on-board using data from available attitude sensors. To meet mission pointing accuracy requirements, the attitude sensors must be calibrated for instrument biases, scale factors and misalignments immediately after launch and as needed thereafter. Traditionally, the calibration process is performed by an attitude support specialist, often requiring elaborate procedures involving attitude consistency check, trending, and diagnosis expertise. The calibrated parameters are then uplink to the spacecraft. The improved calibration parameters enable the on-board computer to correct attitude sensor data and thus maintain the spacecraft attitude pointing accuracy. The main objective for the current stage of our research is to perform sensor calibration on-board spacecraft.

In our proposed system, during calibration mode, the coordinator will set a goal following a guideline stored in its knowledgebase, perhaps as a set of rules. A typical goal would be, to calibrate a particular sensor. When a goal is set, a number of subsets of sensors associated with the goal is identified. From each of these subsets, an attitude vector is estimated. The resulting attitude vectors are then compared. Standard estimation technique such as Kalman filter can be used for both attitude estimation and inconsistency prediction. An inconsistency that occurs indicates that there are errors in some sensor model parameters. To determine which parameters need adjustment is the job of the diagnoser.

The coordinator must be able to create simple plans subjected to calibration tasks. It should be aware of available sensors, i.e. those with target in field of view, and related resources. This means the spacecraft must be sufficiently equipped with star catalog, and Sun, Earth, Moon ephemeris. Sensor selection scheme associated to each sensor to be calibrated must also be available. The selected sensors should generate a number of attitude vectors, which yield enough information to calibrate the sensor. The coordinator must also be able to do some maneuver planning needed for gyroscope calibration

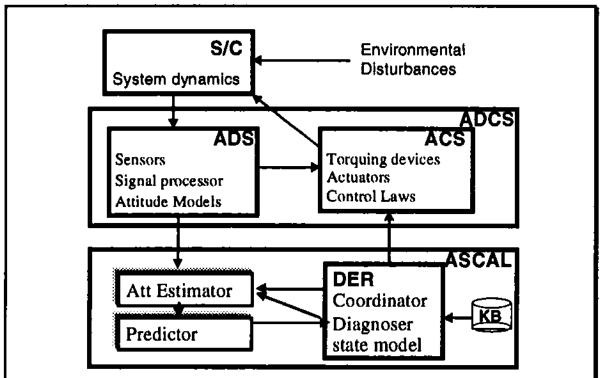

Fig 1. On-board interface between ASCAL and ADCS

Figure 1 shows an interface between ADCS and ASCAL. In this diagram, the estimator and predictor are shown as processes external to the ADS.

In figure 2, Γ is the set of selected sets of sensors. Each sensor model is assumed linear:

$$z_{a_i}(k) = G_{a_i}(p_{a_i})x_a(k) + w_{a_i}$$

where a_i is the i-th sensor in a subset $a \in \Gamma$ and p_{a_i} is the vector of its model parameters. x_a is the attitude vector estimated by the measurements from sensors in a. The inconsistency trend between attitude vectors associated to two different subsets a and b is the difference $T_{ab} = x_a - x_b$. Both inconsistency trend and its slope S_{ab} are modeled linearly as follows

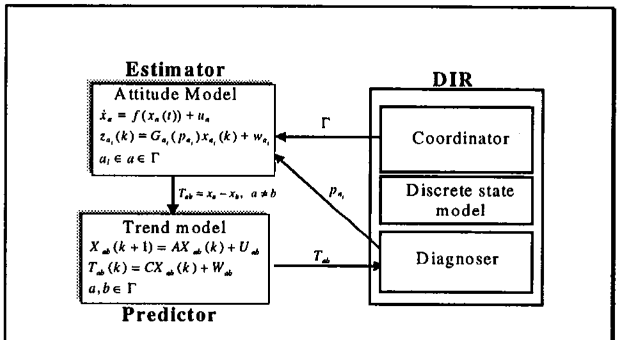

Fig 2. Trend analyzer and diagnoser

$$X_{ab}(k+1) = AX_{ab}(k) + U_{ab}(k+1)$$
$$T_{ab}(k) = HX_{ab}(k) + W_{ab}(k+1)$$

where $X_{ab} = [T_{ab} - W_{ab} \quad S_{ab}]'$

$U_{ab} = [W_{ab} \quad u_{ab}]'$ is a zero mean noise vector

$$A = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix}, \quad H = [1 \quad 0]$$

When one or more T_{ab} display a trend, the diagnoser is activated to determine which parameter of which sensor will need adjustment. The adjusted parameters are fed back to the estimator. The cycle continues until all inconsistencies converge to within an acceptable limit. Human intervention is called for if this process does not converge, and if the diagnoser cannot resolve this problem. In this case, the lessons learned should be added into the DER knowledgebase for future use.

References:

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