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Investigation of Integrated Vehicle Health Management Approaches

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This report is to present the work that was performed during the summer in the Advance Computing Application office. The NFFP (NASA Faculty Fellow Program) had ten summer faculty members working on IVHM (Integrated Vehicle Health Management) technologies. The objective of this project was two-fold: 1) to become familiar with IVHM concepts and key demonstrated IVHM technologies; and 2) to integrate the research that has been performed by IVHM faculty members into the MASTLAB (Marshall Avionic Software Test Lab).

IVHM is a NASA-wide effort to coordinate, integrate and apply advanced software, sensors and design technologies to increase the level of intelligence, autonomy, and health state of future vehicles. IVHM is an important concept because it is consistent with the current plan for NASA to go to the moon, mars, and beyond. In order for NASA to become more involved in deep exploration, avionic systems will need to be highly adaptable and autonomous.

IVHM Activities

The first major initiative took place for IVHM was an IVHM testbed workshop. Attendees of this workshop included representatives from the aerospace industry, from governmental agencies, academia, and other NASA centers. The purpose of IVHM is to increase the safety, affordability, and sustainability of Exploration missions through Integrated Systems Health Management of complex, mission-critical vehicles and systems. Some of the objectives of IVHM includes 1) automated pre-flight readiness checkout, 2) built-in test functionality, 3) automated ground processing, 4) automated systems health assessment, 5) failure management and report, 6) integrated real-time fault diagnosis, and 7) trending and prognostics. These objectives will enable GN & C capabilities, advanced mission planning and flight operations, advanced crew escape & survival/payload recovery, advanced automated rendezvous and capture, and advanced checkout, control and maintenance system.

Vehicle Health Management History

One of the things that were identified at the IVHM testbed workshop was that IVHM has a history of having many different paradigms.

- *FDRI (Fault Detection, Isolation, and Reconfiguration)* was a paradigm that was used in the aerospace industry in the 60s and 70s.
- *Autonomy*-some believed that IVHM was a subset of autonomy and there are those who believe that autonomy is a subset of IVHM.
- VHM_a(Vehicle Health Monitoring)- evolved from FDIR.
- *SHM (Systems Health Management)*- this was the first attempt to integrate safety, reliability, fault management, testability and cost benefit analysis into a common framework. This is also defined independently as Structural Health Management.
- VHM_b*(Vehicle Health Management)*-management aspect spans autonomous reconfigurations well as the resources required to safely and most cost effectively achieve mission goals.

- *IM(Informed Maintenance)*-this is also referred to as condition based maintenance.*RSO(Resilient Systems & Operations)*-this is Level 2 IVHM project under the Design for Safety Program).
- *IIVM (Intelligent Integrated Vehicle Management)*-this is a paradigm that has been developed from the CRAI activities.

There is a difference between VHM_a and VHM_b. It is considered among many that the only way to assure the goals of IVHM will be to include an integrated capability for automating the maintenance and operation of vehicles. That would mean a significantly different use of avionics systems as opposed to the way they are now employed. This is the concept of vehicle health management as opposed to simply vehicle health monitoring. Such a concept implies the ability to fully monitor the operational functions of the target vehicle and to have built-in systems abilities to do something with the information derived from that monitoring. Another critical aspect of IVHM is that information is generated and acted upon rather than merely acquiring data and presenting it for later manipulation and use. The integrated system will require many modules as subcomponents such as structural surveillance systems, active structural controls and adaptation, flight controls and control surfaces, propulsion management and surveillance, guidance and navigation.

IIVM for NFFP Project

As a part of the overall goal of developing Integrated Vehicle Health Management (IVHM) systems for aerospace vehicles, the NASA Faculty Fellowship Program (NFFP) at Marshall Space Flight Center has performed a pilot study on IVHM principals which integrates researched IVHM technologies in support of Integrated Intelligent Vehicle Management (IIVM). The framework integrates advanced computational techniques with sensor and communication technologies for spacecraft that can generate responses through detection, diagnosis, reasoning, and adapt to system faults in support of IIVM. These real-time responses allow the IIVM to modify the affected vehicle subsystem(s) prior to a catastrophic event. Furthermore, the objective of this pilot program is to develop and integrate technologies which can provide a continuous, intelligent, and adaptive health state of a vehicle and use this information to improve safety and reduce costs of operations. Recent investments in avionics, health management, and controls have been directed towards IIVM. As this concept has matured, it has become clear the IIVM requires the same sensors and processing capabilities as the real-time avionics functions to support diagnosis of subsystem problems. New sensors have been proposed, in addition, to augment the avionics sensors to support better system monitoring and diagnostics. As the designs have been considered, a synergy has been realized where the real-time avionics can utilize sensors proposed for diagnostics and prognostics to make better real-time decisions in response to detected failures. IIVM, as shown in figure 1, provides for a single system allowing modularity of functions and hardware across the vehicle. The framework that supports IIVM consists of 11 major on-board functions necessary to fully manage a space vehicle maintaining crew safety and mission objectives: Guidance and Navigation; Communications and Tracking; Vehicle Monitoring; Information Transport and Integration; Vehicle Diagnostics; Vehicle Prognostics; Vehicle mission Planning; Automated Repair and Replacement; Vehicle Control; Human Computer Interface; and Onboard Verification and Validation. Furthermore, the presented framework provides complete vehicle management which not only allows for increased crew safety and mission success through new intelligence capabilities, but also yields a mechanism for more efficient vehicle operations. The representative IVHM technologies for IIVM includes: 1) robust controllers for use in re-usable launch vehicles, 2) scaleable/flexible computer platform using heterogeneous communication, 3) coupled electromagnetic oscillators for enhanced communications, 4) Linux-based real-time systems, 5) genetic algorithms, 6) Bayesian Networks, 7) evolutionary algorithms, 8) dynamic systems control modeling, and 9) advanced sensing capabilities.

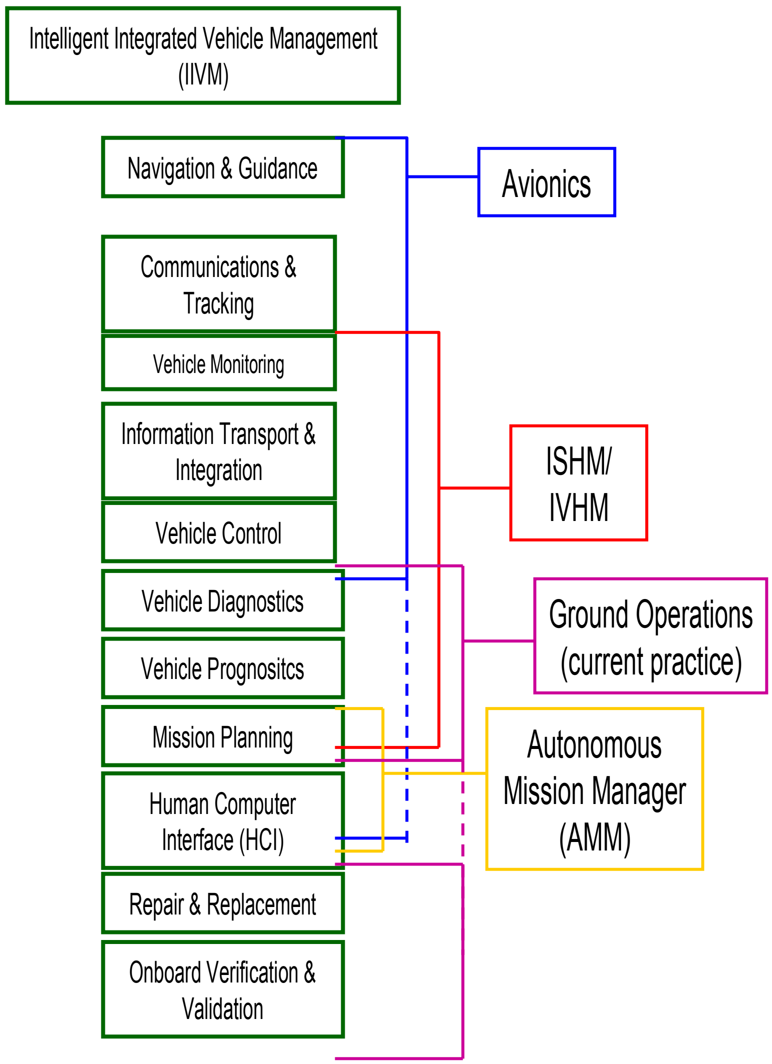

Figure 1: Proposed Intelligent Integrated Vehicle Health Management Framework

IVHM TECHNOLOGIES

The automotive industry is leading the development of on-board and ground-based diagnostics. Nissan has developed a system called the Electronic Concentrated Control System (ECCS) which provides Diagnostic Trouble Codes (DTCSs) for technicians to reference in the Diagnostic Manual via CD-ROM. Similarly, Ford states that 70,000 technicians are using their two volume "ultimate toolbox" Service Manual by referencing on-board provided Service Codes to obtain test procedures, test guides and wiring diagrams for all unique engine configurations[1].

Integrated Diagnostics (ID) was developed by the Boeing and Honeywell Corporations for the 777 aircraft called the Aircraft Information Management System (AIMS)[2]. This integrated a number of aircraft functions, previously in separate Line Replaceable Units (LRUs), into a single central computer system including the Central Maintenance Computer (CMC). Boeing Phantomworks is developing the Informed Maintenance and Support System (IMSS) which is a maintenance concept that integrates the vehicle, maintenance scheduling, maintenance technicians, technical data, support equipment and logistics system into a tightly managed support system.

Lockheed-Martin is developing the Joint Distributed Information Systems (JDIS) for the Joint Strike Fighter (JSF)[3]. It includes on-board Mission Systems and Vehicle Maintenance System (VMS) as well as ground based Prognostics Health and Management (PHM). JSF will integrate on-board status with ground based logistics and training databases to optimize vehicle availability. Lockheed-Martin Skunkworks' Integrated Health Management and Data Advisory Tool (IHMDAT) for X-33 is a ground-based system engineering support tool that provides console operators significant added capability for making Launch Commit Criteria (LCC) and maintenance decisions.

Informed Maintenance for the Space Shuttle has focused on Predictive Health and Reliability Management (PHARM)[4]. This system collects and analyzes sensor data, trend failures, and notifies logistics when a replacement part will be required. For X-34, the NASA IVHM Technology Experiment for X-vehicles (NITEX) was to have monitored main engine parameters throughout all mission phases using detailed diagnostic algorithm to detect degraded component performance as well as a system-level health monitoring system that integrates information from multiple components to perform real-time fault detection, isolation and recovery. In addition, the experiment would have demonstrated the use of an advanced, user friendly ground station that combines information provided by the on-board IVHM software with information obtained while the vehicle was on the ground to provide high-level status information on the health of the vehicle along with the ability to access more detailed information when required.

X-37 IM is being developed by Boeing and NASA[5]. This system will focus on the health summary information provided by the IVHM flight experiment as well as additional information already available in the vehicle's telemetry stream. It will be included into an overall rapid vehicle turnaround demonstration plan utilizing a wireless work documentation system and a wireless communication system for maintenance personnel.

IVHM Software

Livingstone was developed at Ames Research Center. It performs system-wide fault detection and isolation; and it can detect sensor faults and multi-point failures. This software compares values with what they should be according the model and the command stream. When the values do not match the software will signal a fault to find one that matches the data; it also searches the space of possible actions to find a recovery action sequence. This software was used on Deep Space One; it was also applied to X-34, X-37 and ISS. It will also fly on EO-1.

SHINE is a rule-based high speed inference system developed at JPL. This is a reusable knowledge base software tool for the real-time monitoring, diagnosis, prognosis and analysis of complex systems through forward and backward inferencing. This software outperforms most commercial products by at least two orders of magnitude. Some of the benefits of SHNE is that it provides a 100x o 1000x improvement in inference, and up to 10,000x reduction in execution environment. Inferencing speed is achieved from a sophisticated mathematical transformation based on graph-theoretic data flow analysis. This reduces the complexity of the conflict-resolution match cycle by the transforming of the knowledge base into a data flow diagram. The data flow diagram is automatically translated to various target programming languages for efficient representation and execution.

BEAM was also developed at JPL. BEAM monitors a signal and learns the normal behavior of a signal; it flags anything that is out of the norm. It also can be programmed, for instance, to turn on a valve so that the pressure can be at a designated psi. It also knows what pressure should be in the valve at a position, x. BEAM has been used as a monitor to interface with modeled-based reasoners like Livingstone.

TEAMs is a modeled-based reasoner that was developed b by QUALTECH Systems based out of Connecticut using NASA SBIR/STTR funding. This software was tested by Ames Research Center. This software only models failure models, and has been applied to X-33.

Data mining is a tool to help analyze data from anomalous conditions and significant features both supervised (examples of faults) and unsupervised (only nominal).

ON-GOING IVHM ACTIVITIES

This research work will be continued throughout the year under the NAFP (NASA Administrators fellowship program. The next step is to integrate the IVHM technologies that were researched during the summer into the MASTLA.

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