Multiple Information Agents for Real-Time ISHM: Architectures for Real-Time Warfighter Support

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Abstract

In the real-time battlefield arena, situational awareness becomes critical to making the right decisions and achieving the overall goals for the system. The key to Situational Awareness is not simply collecting and disseminating data, but it is actually getting the right information to the right users at the right time. In ground processing systems, various sensors, spacecraft, and other data sources gather and generate data different relevant contexts. What is required is an Integrated System Health Management (ISHM) processing architecture that allows users to turn the data into meaningful information, and to reason about that information in a context relative to the user at that time, and to update the information real-time as the situation changes. In short, it is imperative that the information processing environment be efficient, timely, and accurate. Described will be an Intelligent Information Agent processing environment which allows data to be processes into relevant, actionable knowledge. Based on the technologies described above, situational management is one of the most innovative components this processing systems. Utilizing the Artificial Cognitive Neural Framework (ACNF) (Crowder, 2005), it can provide real-time processing and display of dynamic, situational awareness information.

I. Introduction

Even in Service Oriented Architectures, true ISHM situational awareness is difficult because the enterprise has to become more aware, more flexible, and more agile than ever before. Information gathering, processing, and analyzing must be done continually to keep track of current trends in the context of the current situations, both local and overall, and provide timely and accurate knowledge to allow the users to anticipate and respond to what is happening in a changing environment. To achieve the combination of awareness, flexibility, and agility means supporting dynamic and flexible processes that adapt as situations change. This is possible with learning, evolving, Intelligent Information Agents, like those in the described here.

The Data Steward Agents will support growing volumes of data and allow Reasoner Agents to produce accurate and relevant metrics about past, current, and future situations (prognostics). Through inter-agent communication, they provide control and visibility into the entire ground processing enterprise. This is made possible by integrating the processing environment into the flexible, distributed, Service Oriented Architecture (SOA) that enables secure collaboration, advanced information management, dynamic system updated, and customer, rule-based processes (Advisor Agents).

The inter-agent communication allows shared awareness which, in turn, enables faster operations and more effective information analysis and transfer, providing users with an enhanced visualization of overall constellation and situational awareness across the ground processing system’s Enterprise Infrastructure. This Intelligent Agent-based system can deal with massive amounts of information to levels of accuracy, timeliness, and quality never before possible.

Even applications that deal with object-oriented technologies fail to achieve the goals of awareness, flexibility, and agility because their processes are hard coded into the applications. The flexible, learning, adapting Intelligent Software Agents of the ACNF processing framework can adapt, collaborate, and provide the increased flexibility required in a growing, changing signal/source environment (Crowder, 2006).

II. Integrated System Health Management

Following the evolution of diagnostic systems, prognostic initiatives started to be introduced in order to try to take advantage of the maintenance planning and logistics benefits. However, the early prognostic initiatives often were driven by in-field failures that resulted in critical safety or high-cost failures, and thus retrofitted technology was hard to implement and costly to develop. Hence diagnostic and prognostic system developers found the need to analyze and describe the benefits associated with reducing in-field failures and their positive impact on safety, reliability, and overall lifecycle-cost reduction. This has lead to many cost-benefit analyses and ensuing discussions and presentations to engineering management about why the diagnostic and prognostic technologies need to be included in the design process of the system and not simply an
afterthought once field failures occur. This has lead us to the point where many complex vehicle/system designs, like DD(X), GPS OCX, and various weapon systems are now developing “designed in” health management technologies that can be implemented within the Integrated Maintenance & Logistics and supports the system throughout its life time. This “designed in” approach to health management is performed with the hardware/software design itself and also acts as the process for system validation and managing inevitable changes from in-field experiences and evaluating system design tradeoffs, as shown in Figure 1 (Crowder, 2007).

Realizing such an approach will involve synergistic deployments of component health monitoring technologies, as well as integrated reasoning capabilities for the interpretation of fault-detect outputs. Further, it will involve the introduction of learning technologies to support the continuous improvement of the knowledge enabling these reasoning capabilities. Finally, it will involve organizing these elements into a maintenance and logistics architecture that governs integration and interoperability within the system, between its on-board elements and their ground-based support functions, and between the health management system and external maintenance and operations functions. Here we present and discuss the required prognostic functions of an Integrated Health Management System that, if applied correctly, can directly affect the operations and maintenance of the equipment and positively affect the lifecycle costs.

A comprehensive health management system philosophy integrates the results from the monitoring sensors all the way through to the reasoning software that provides decision support for optimal use of maintenance resources. A core component of this strategy is based on the ability to (1) accurately predict the onset of impending faults/failures or remaining useful life of critical components and (2) quickly and efficiently isolate the root cause of failures once failure effects have been observed. In this sense, if fault/failure predictions can be made, the allocation of replacement parts or refurbishment actions can be scheduled in an optimal fashion to reduce the overall operational and maintenance logistic footprints. From the fault isolation perspective, maximizing system availability and minimizing downtime through more efficient troubleshooting efforts is the primary objective.

In addition, the diagnostic and prognostic technologies require an integrated maturation environment for assessing and validating prognostics and health management (PHM) system accuracy at all levels in the system hierarchy. Developing and maintaining such an environment will allow for inaccuracies to be quantified at every level in the system hierarchy and then be assessed automatically up through the health management system architecture. The final results reported from the system-level reasoners and decision support is a direct result of the individual results reported from these various levels when propagated through. Hence an approach for assessing the overall PHM system accuracy is to quantify the associated uncertainties at each of the individual levels, as illustrated in Figure 2, and build up the accumulated inaccuracies as information is passed up the system architecture. This type of hierarchical verification and validation (V&V) and maturation
process will be able to provide the capability to assess diagnostic and prognostic technologies in terms of their ability to detect subsystem faults, diagnose the root cause of the faults, predict the remaining useful life of the faulty component, and assess the decision-support reasoner algorithms. Specific metrics include accuracy, false-alarm rates, reliability, sensitivity, stability, economic cost/benefit, and robustness, just to name a few. Cost-effective implementation of a diagnostic or prognostic system will vary depending on the design maturity and operational/logistics environment of the monitored equipment. However, one common element to successful implementation is feedback. As components or LRUs are removed from service, disassembly inspections must be performed to assess the accuracy of the diagnostic and prognostic system decisions (Crowder, 2006). Based on this feedback, system software and warning/alarm limits should be optimized until desired system accuracy and warning intervals are achieved. In addition, selected examples of degraded component parts should be retained for testing that can better define failure progression intervals.

Figure 2 – Functional Layers in an ISHM System

A systems-oriented approach to prognostics requires that the failure detection and inspection-based methods be augmented with forecasting of parts degradation, mission criticality and decision support. Such prognostics must deal not only with the condition of individual components, but also the impact of this condition on the mission-readiness and the ability to take appropriate actions (Crowder, 2003). However, such a continuous health management system must be carefully engineered at every stage of a system design, operation and maintenance. Figure 2, above, illustrates the overall ISHM process which includes modeling, sensing, diagnosis, inference & prediction (prognostics), learning, and updating. The two most important steps in this process are 1) fault detection & diagnosis and 2) prognostic reasoning (prediction):

A. Fault Detection and Diagnostic Reasoning

This determines if a component/subsystem/system has moved away (degraded) from nominal operating parameters, along a known path, to a point where component performance may be compromised. Novelty detection determines if the component has moved away from what is considered acceptable nominal operations and away from all known fault health (diagnostics as defined above) propagation paths (Crowder, 2006).

B. Prognostic Reasoners

The purpose of reasoners is the assessment of the component’s current health and a prediction of the component’s future health, or Useful Remaining Life (URL). There are two variations of the prediction problem. The first prediction type may have just a short horizon time—is the component good to fly the next mission? The second type is to predict how much time we have before a particular fault will occur and, by extension, how much time we have before we should replace it. Or it may be longer term—tell me when to schedule removal of an engine for overhaul.
Accurate prognosis is a requirement for implementing Integrated System Health Management (ISHM). The creation of a prognostic algorithm is a challenging problem. There are several areas that must be addressed in order to develop a prognostic reasoner that achieves a given level of performance. Figure 3 illustrates the prognostic process utilizing Intelligent Information Agents.

![Figure 3 – Prognostic Process Utilizing IA](image)

C. The Prognostics Process

The prognostics component (utilizing Analyst Agents) provides specific information to the Advisor Agents about the system’s state of health, status, RUL, confidence and recommendations. A graphical representation of the inputs and outputs to the Prognostics Analyst Agent is illustrated in Figure 4. The description of the inputs and outputs are given below in Figure 5.

![Figure 4 – Prognostic Analyst Agent Processing](image)
D. Automated Decision Making

The Automated Decision Making component utilized Advisor agents that acquire data primarily from Diagnostic and Prognostic Analyst Agents. The primary function of the Automated Decision Advisor Agents is to provide recommended actions and alternatives and the implications of each recommended action. Recommendations may include maintenance action schedules, modifying the operational configuration of assets and equipment in order to accomplish mission objectives, or modifying mission profiles to allow mission completion.

The Automated Decision Making Advisor Agents take into account operational history (including usage and maintenance), current and future mission profiles, high-level unit objectives, and resource constraints. This is always a Human-in-the-Loop to assess the correctness of major decisions and adjust the decision process. Figure 6 illustrates the Decision Making Process.

III. Prognostic Technologies: Intelligent Information Agents (I²A)

The I²A architecture is a framework for constructing a hybrid system of Intelligent Information Software Agents. This provides a productivity toolkit for adding intelligent software agent functions to applications and modern architectural frameworks. This provides the constructs for building multi-agent intelligent autonomic systems. This includes the
A framework for providing business rules and policies for run-time systems, including an autonomic computing core technology within a multi-agent infrastructure. Figure 7 illustrates the Intelligent Information Agents for the I²A framework.

A. The I²A Framework

The I²A hybrid computing architecture uses genetic, neural-network and fuzzy logic that are used to integrate diverse sources of information, associate events in the data and make observations (Crowder, 2002). When combined with a dialectic search, the application of hybrid computing promises to revolutionize information processing. The dialectic search seeks answers to questions that require interplay between doubt and belief, where our knowledge is understood to be fallible. This ‘playfulness’ is key to hunting in information and is explained in more detail in the section that address the Dialectic Argument Structure.

Figure 7 – Intelligent Information Agents

Figures 8, 9, and 10 further explain this. The dialectic search avoids the problems associated with analytic methods and word searches. In its place, information is used to develop and assess hypotheses seeded by a domain expert. This is achieved using I²As that augments human reason by learning from the expert how to argue and develop a hypothesis. Using Franklin and Graesser’s definition for a software agent, we would define the I²A as: an autonomous agent situated in and part of the information ecosystem, comprehending its environment and acting upon it over time, in pursuit of its own agenda, so as to effect what it comprehends in the future. The I²As have certain abilities that distinguish it from software objects and programs and provide it with the intelligence it needs to mimic human reasoning (Crowder, 2002).

This process includes Search Information Agents that mine through multiple sources to provide data/information to other Intelligent Information Agents throughout the ISHM processing environment. This is called the Federated Search, shown in Figure 11 (Crowder, 2006).

Notice that this process includes utilizing Subject Matter Experts (SMEs) to provide initial information to ISHM. The system cannot just spontaneously generate initial knowledge, it must be fed information to learn from (not just train as in traditional neural network systems, but learn the information). This includes a learning based question and answer processing architecture that allows the ISHM processing environment to ask questions, based on contextual understanding of the information it is processing, and extract answers, either from its own inference engines, its own memories, other information contained in its storage systems, or outside information from other information sources, or SMEs. This process is illustrated in Figure 12 (Crowder, 2004).

- **Intelligence Network**: finding experts and information to answer questions
- **Answer Extraction**: finding information that provide answers
- **Situation Analysis**: finding situations that require active investigation

*Figure 7 – Intelligent Information Agents*
Figure 8 – The Data Steward and Advisor Agents

Generates & maintains the meta-data to find and extract data-information from heterogeneous systems.

Generates & maintains topic maps required to find relevant data and experts.

Figure 9 – The Reasoner Agent

Analyze questions and relevant source fragments to provide answers and develop ontological rules.

Figure 10 – The Analyst Agent

Patterns of thinking are used to direct Q&A generation and creation of situational analyses with integrated explanations.

- Expanded questions & answers are used to learn from collected information
- Evolve Pattern Languages that best explain the situational being analyzed
- Interactive sharing of knowledge between agents and end-users
This allows the modern ISHM architecture to comprise a host of functional capabilities:

1. Sensing and data acquisition
2. Signal processing, conditioning and health assessment Diagnostics and prognostics
3. Decision reasoning

In addition, an intelligent Human System Interface (HSI) is required to provide the user with relevant, context-sensitive information about system condition. Utilizing the Intelligent Information Agent Architecture described here, an ISHM could provide a complete range of functionality from data collection through recommendations for specific actions. The key functions that an I²A ISHM system could facilitate include:

1. Sensing and data acquisition (Data Steward Agents)
2. Signal Processing and feature extraction (Reasoner Agents)
3. Production of alarms or alerts (Advisor Agents)
4. Failure or fault diagnosis and health assessment (Analyst Agents)
5. Prognostics: projection of health profiles to future health or estimation of RUL (remaining useful life) (Analyst and Advisor Agents)
6. Decision reasoning: recommendations or evaluation of asset readiness for a particular operational scenario (Advisor Agents)
7. Management and control of data flows and/or test sequences (Data Steward Agents)
8. Management of historical data storage and historical data access (Data Steward Agents)
9. System configuration management (Data Steward Agents)
10. Human System Interface (Interface Agents – Advisor Agents)

The use of Intelligent Information Agents allows both granular approaches (individual agents implementing individual functions) and integrated approaches (individual agents collaborating together to integrate a number of functions). The ISHM architecture would take into account data flow requirements to control flexibility and performance across the ISHM system. This allows the I²A ISHM system to support the full range of data flow requirements through both real-time and event-based data reporting and processing. Time-based reporting is further categorized as periodic or aperiodic. The event-based reporting and processing is based upon the occurrence of events (e.g., exceeding limits, state changes, etc.).

B. The Dialectic Argument Search

The Dialectic Search uses the Toulmin Argument Structure to find and relate information that develops a larger argument, or intelligence lead. The Dialectic Search Argument (DSA), illustrated in Figure 13, serves two distinct purposes. First, it provides an effective basis for mimicking human reason. Second, it provides a means to glean relevant information from the Topic Map and transform it into actionable intelligence (practical knowledge.) These two purposes work together to provide
an intelligent system that captures the capability of the ISHM operator to sort through diverse information and find clues (Crowder, 2003).

Figure 12 – Question and Answer Architecture for ISHM

Figure 13 – The Dialectic Argument Structure

Figure 15 illustrates a possible Intelligent Software Agent Architecture that could be used to implement the DAS: three different agents, the Coordinator, the DAS and the Search, work together, each having its own learning objectives.

IV. Conclusion and Discussion

The inter-agent communication allows shared awareness which, in turn, enables faster operations and more effective information analysis and transfer, providing users with an enhanced visualization of overall constellation and situational awareness across an ISHM infrastructure. The Intelligent Agent-based ISHM can deal with massive amounts of information to levels of accuracy, timeliness, and quality never before possible. The Data Steward Agents will support growing volumes of data and allow applications that deal with object-oriented technologies to achieve the goals of awareness, flexibility, and agility. The flexible, learning, adapting Intelligent Software Agents of the ISHM system can adapt, collaborate, and provide the increased flexibility required in a growing, changing environment.
References