Advances in Reliability, Safety and Security

ESREL 2024
Collection of Extended Abstracts

Multi-Dimensional Health Assessment Of Complex Systems Based On Health State Hierarchical Flow Chart

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Keywords: health assessment, multi-dimensional, hierarchical, complex systems

This paper presents a multi-dimensional hierarchical health assessment system, an efficacious methodology based on the health state hierarchical flow chart and coupled multi-dimensional indicators, for comprehensive health assessment of complex systems. To quantitatively assess the health state indicators, a dynamic health state hierarchical flow chart modeling method, suitable for typical function structure models, is proposed. The practical application of this method on the satellite attitude and orbit control system demonstrates its effectiveness. It establishes a bridge from numerous satellite telemetry parameters to the system-level health state, providing valuable guidance for task determination and maintenance decisions. This study offers a more reliable and universal methodology for the comprehensive health assessment of complex systems, contributing significantly to the field.

There are a few studies on the health assessment of complex systems. Existing methodologies require various knowledge and expertise of evaluation objects, which results in the difficulty and workload of establishing health assessment models.

To address the above challenges, the multi-dimensional hierarchical health assessment system is proposed to deliver precise and comprehensive health assessment results for complex systems. Most products, especially complex systems, can typically be broken down into multiple units at different levels based on their function structure relationships. The health state of units at all levels is represented by two indicators: task health index and risk health index. In alignment with the fundamental purpose of health assessment, the task health index of unit measures a unit's capability to fulfill intended tasks in current state, while the risk health index measures a unit's capacity to withstand risks during task completion.

The process of multi-dimensional hierarchical health assessment for complex systems can be divided into:

(1) *Establishing the health state hierarchical flow chart*

The health state hierarchical flow chart is a clear and hierarchical abstraction of the interconnections among the units of a complex system. As the system or task changes, the health state hierarchical flow charts can be dynamically constructed, maintaining the basic modelling approach intact.

(2) *Acquiring the health indexes of the components*

The identification of the lowest level units, also referred to as components, necessitates a consideration of the feasibility of system decomposition and the requirements of health assessment. The task health index and risk health index of the component are equal and can be evaluated using data-driven or model-driven methodologies.

(3) *Calculating the task health indexes and risk health indexes of upper-level units*

Based on the health state of the component-level units and the health state hierarchical flow charts, the multi-dimensional hierarchical health assessment system calculates the task health index and risk health index of the units from the bottom level to the top level. The task health indexes and the risk health indexes of all units provide a comprehensive understanding of the system's state, and guide maintenance and task decisions.

The satellite attitude/orbit control system (AOCS) of satellite is a typical hierarchical complex system. During the normal orbit of the satellite around the earth, the main task of the AOCS is to keep the satellite in orbit and correct attitude. Under this task, the health state hierarchical flow chart of the satellite AOCS is shown in Fig. 1.

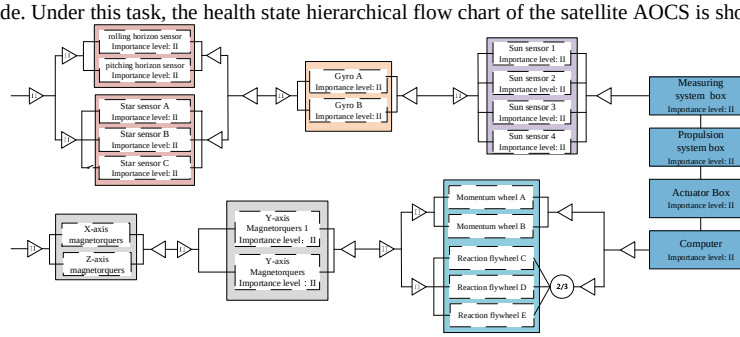

Fig. 1. The health state hierarchical flow chart of the satellite AOCS.

The telemetry data of satellite A and satellite B from December 1, 2012 to November 30, 2013 is chosen to assess the health status of the AOCS. The AOCS task health index of both satellites remained close to 1 during the year as shown in Fig. 2(a), but the risk health index of the Satellite A has a more obvious downtrend than the Satellite B as shown in Fig. 2(b), the rationality of which can be verified by the fact that satellite A launched two and a half years earlier than satellite B. The multi-dimensional health assessment information can help ground command and control staff make better decisions.

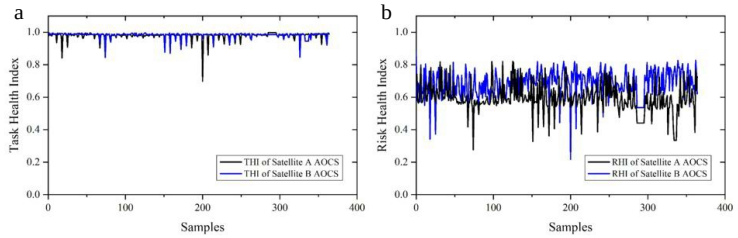

Fig. 2. (a) THI of Satellite A and Satellite B AOCS; (b) RHI of Satellite A and Satellite B AOCS.

The findings of this study underscore the efficacy and indispensability of the multi-dimensional hierarchical health assessment system. The combination of task health index and risk health index, in contrast to the traditional single health indicator, can furnish an early warning of a system's deteriorating health state. The proposed methodology has demonstrated its industrial advantages on the satellite health assessment and management platform and holds considerable potential for application to other complex systems.

Acknowledgements

The authors express gratitude to the Stable Support Research Project of the National Key Laboratory of Science and Technology on Reliability and Environmental Engineering for the funding support (Grant No. 6142004WDZC210401).

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