A Multi-agent Based Satellite Health Management System Architecture and Implementation Scheme

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Abstract. Health management is one of the important contents of satellite intelligent and autonomous management. Its goal is to ensure the normal operation of satellite system on orbit, improve system reliability and safety, and reduce the dependence on ground and human resources. In this paper, we analyze the task requirements faced by satellite intelligent health management, and propose a satellite distributed health management system architecture based on Multi-Agent System. Combined with the layered model and system characteristics of the satellite on-board integrated electronics system, the scheme design of the health management system is completed, and a health management system architecture conforming to the integrated electronic standard is established, which provides a feasible scheme for future engineering design.

Keywords: Health management · Multi-agent system · Intelligent

1 Introduction

The Modern satellite system is a complex system integrated by machinery, electricity, and heat. Because of its harsh space operation environment, its work is prone to failure [1]. Moreover, due to the high difficulty of satellite in orbit maintenance, redundancy designs are generally taken to improve the reliability of long-term operation. Therefore, fault diagnosis, processing and recovery methods have always been one of the focuses of satellite system research. Satellite fault diagnosis focuses on how to timely and accurately diagnose the faults that have occurred or predict the faults that will occur, so as to take measures to avoid the spread of faults and reduce losses. In recent years, with the rapid development of on-board electronics system technology and the growing maturity of artificial intelligence technology, the level of satellite intelligence has also been greatly improved. The onboard autonomous processing capacity of traditional satellites is very limited, and health management mainly depends on the monitoring and judgment of ground systems, which can no longer meet the needs of long-term on orbit operation of complex systems in the future.

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In this paper, according to the characteristics of the future intelligent satellite system, a satellite health management system architecture based on Multi-Agent System (MAS) is proposed. Combined with the engineering constraints of the satellite integrated electronics system, the health management system scheme design was completed, and solutions were provided for communication mechanism, system expansion and other problems, forming a system architecture that conforms to the integrated electronics standard, providing reference for future engineering design.

2 Requirements and Challenges of Satellite Intelligent Fault Diagnosis

With the deep application of computer technology and artificial intelligence technology, future space missions will require more and more intelligent and autonomous satellites. For example, due to the limitation of measurement and control conditions in deep space exploration, the traditional method of dealing with faults by making plans and sending orders from the ground is far from meeting the task requirements. Generally, satellites are required to be able to independently complete system status monitoring, judge health status and formulate appropriate commands to deal with various faults and complete various established tasks.

On the other hand, with the increasing number of satellites in orbit, the pressure on the ground operation management system is increasing. With the existing management mode, the diagnosis and handling of failures are heavily dependent on manual work, which may easily lead to a long time of satellite anomaly processing, cause the spread of failures, and even bring disastrous consequences. Therefore, through intelligent and autonomous health management, satellites can quickly locate known faults themselves, make corresponding disposal and timely complete fault recovery; For unknown faults or complex faults, it can also provide more reference information for satellite ground managers.

Based on various requirements of satellite system engineering development and in orbit operation, the design objectives of satellite intelligent fault diagnosis mainly include the following aspects.

a. Fault detection and diagnosis: it can timely detect the faults occurring on the satellite, and quickly diagnose and locate the faults.
b. Self-disposal of real-time faults: according to the specific faults detected and diagnosed, evaluate their severity and development trend, timely provide fault countermeasures, and independently complete system reconfiguration, fault recovery or degraded operation according to available resources and task requirements to ensure the safety of satellite operation.
c. Fault and life prediction: find the fault trend in advance, deploy corresponding prevention and reconstruction strategies, and take measures in time to minimize the occurrence of serious faults and ensure the reliable and stable operation of the satellite.
d. Health status assessment: regularly conduct comprehensive analysis on the status of satellites, master the health of systems, subsystems, and equipment of satellites

in orbit, provide reference for operation management, and achieve the purpose of improving the overall availability of satellite systems.

The satellite system is generally composed of multiple subsystems with different functions to complete the system tasks together. The functions and implementation methods of different subsystems vary greatly. The stand-alone machines, components and software running in some subsystems are also different. With the increasingly powerful function of modern satellites, the complexity of the system is further improved, and the heterogeneity of the system is more significant. Therefore, the failure modes, detection methods and diagnosis methods of the objects faced by the satellite system health management are greatly different from each other. If they are all managed in the satellite data tube or the satellite affairs system, the software structure and functions will be too complex. Moreover, due to the limitation of on-board computing capacity and resources, it is difficult to centralize the implementation of complex diagnostic algorithms, comprehensive evaluation and intelligent decision-making in engineering.

On the contrary, if all subsystems independently manage their own health, it is difficult to achieve overall coordination, and the effectiveness of fault diagnosis and the completeness of disposal strategies are insufficient. In particular, for the failure modes with related relationships, different subsystems may have conflicts in operation, which may bring potential system security risks.

The health management system based on MAS can effectively solve the above problems. The function of health management is decomposed and abstracted through MSA to build a health management system that is organically integrated with the integrated electronics system and can be flexibly expanded.

Because different agents in the same system can be heterogeneous, the MAS technology has a very strong expression ability for complex systems. It provides a unified model for various actual systems, thus providing a unified framework for the research of various systems. Its application field is very broad [2].

3 Development and Application of Multi-agent System Theory

The application research of multi-agent technology originated in the 1980s and was widely recognized in the mid-1990s. It has become a hot spot in the field of distributed artificial intelligence since its development [3]. In the field of artificial intelligence, agent usually refers to an active entity with knowledge objectives and capabilities, and can make reasoning decisions independently or under a little guidance of people. It is a computer system in a specific environment. Agent generally has such attributes as autonomy, social ability, reaction ability, spontaneous behavior, mobility, reasoning ability, planning ability, learning and adaptability [4]. A MAS is a collection of multiple agents, whose multiple agent members coordinate and serve each other to jointly complete global or local tasks [5]. The main goal of MAS is to solve large-scale complex problems beyond the ability of a single agent through an interactive community composed of multiple agents, and to decompose large and complex systems into small, mutually communicating and coordinated systems that are easy to manage. On the one hand, the activities of each agent member in the MAS system are autonomous and independent, and their own goals and behaviors are not limited by other agent members. On the other hand, agent members resolve their conflicts and contradictions through competition and negotiation mechanisms, and jointly complete the overall task goal. Multi agent system provides a new method to control large-scale distributed and adaptive complex systems, such as process control, intelligent human-computer interaction, and distributed computing [6].

The advantages of MAS in solving practical problems are mainly shown in the following aspects:

a. The independence and autonomy of different agents in MAS can enable them to have the ability of autonomous reasoning and planning, and can be used to solve different sub problems by selecting appropriate strategies;
b. MAS has good modularity and scalability, supports distributed applications, helps solve the management and expansion problems of large and complex systems, and reduces the total system cost;
c. MAS reduces the complexity of the system and single agent problem solving by constructing multi-level and diversified agents to solve the complex system after decomposition;
d. Agents in MAS communicate with each other, coordinate with each other, and solve problems in parallel, which can effectively improve the ability to solve problems, and solve large-scale complex problems through mutual coordination;
e. Multi agent technology breaks the limitation of using only one expert system in the field of artificial intelligence. In the MAS environment, different experts in various fields may cooperate to solve problems that one expert cannot solve or cannot solve well, improving the ability of the system to solve problems;
f. Different agents can be different individuals or organizations, developed with different design methods and computer languages, so they may be completely heterogeneous and distributed.

As a whole, the MAS needs different agents to cooperate with each other to achieve the overall task of the system. Interoperability between agents is one of the core issues of MAS. Agents within the same MAS or between different MASs must rely on communication mechanisms to share knowledge and information, interact and negotiate, and then cooperate to solve complex heterogeneous problems. Building MAS must have a set of communication language and data model standards to realize the interoperability between agents, and a set of perfect top-level mechanisms to realize the management and coordination of all agents.

The Fig. 1 shows the MAS's model recommended by FIPA (Foundation for Intelligent Physical Agents) [7].

According to the above model, a MAS consists of the following parts.

Message Transport System (MTS) provides communication services between different agents.

Agent Management Service (AMS) is responsible for managing and coordinating the work of all agents in the MAS.

Directory Facilitator (DF) provides directory retrieval services for various agents.

Function Agents (Agent1~N) corresponding to different tasks.

The Non-Agent connected to the system interacts with other agents through a specific functional agent.

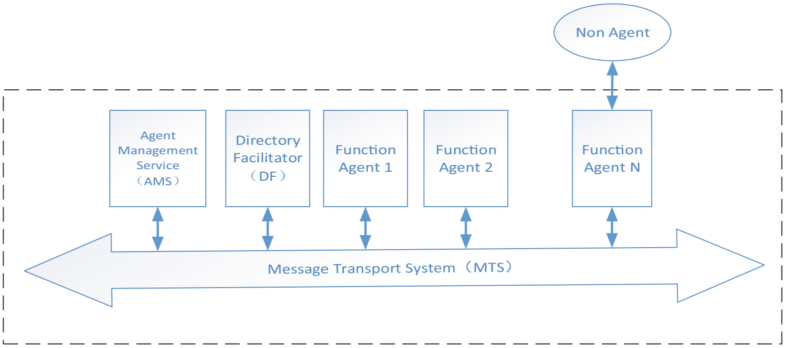

Fig. 1. Reference Model of Multi Agent System

4 Design of MAS Based Satellite Health Management System Framework and Layered Architecture

Referring to the structure of the agent platform shown in Fig. 1 above, and according to the composition of the satellite system structure, the general principles for building the health management MAS are as follows: the health management system adopts a hierarchical architecture, and the corresponding health management agents are configured at different levels of the system to handle health management transactions within this level. Each agent can include monitoring, diagnosis, fault recovery, prediction, and other functions. According to the system composition of the satellite, the regional health management agent is configured according to the different functions of each subsystem to complete local fault diagnosis, disposal, and other functions. Each regional agent synthesizes the results of multiple diagnostic modules from the system level through message transmission, information fusion, joint diagnosis and other technical means within the system agent to form system level fault diagnosis conclusions, and the top level proposes system level disposal measures.

The composition framework of the MAS based satellite health management system built according to the above principles is shown in Fig. 2.

The health management system based on MAS includes the following types of agents:

a. Regional Agent (including subsystem level agent and equipment/component level agent): According to the functional characteristics of the region, independent regional agents are configured for different subsystems and equipments in the satellite, focusing on the internal health management of the subsystem or equipment.
b. System level Agent: Configures system level agent for the whole satellite, responsible for completing system level health management transactions. The system level agent can carry out fault diagnosis, prediction and other health management transactions at the system level according to the status information or diagnosis report send by the regional agent of each subsystem, recheck and evaluate abnormal reports, diagnosis results, disposal strategies, etc. and make decisions. At the same time, relevant system constraints and other inputs should be provided for each regional agent.

c. Coordination Agent: responsible for coordinating the work consistency of different agents, and supervising and managing the working status of subordinate agents. Manage the entrance, exit, parameter configuration, fault tolerance etc. of all agents in the entire health management system.
d. Satellite-ground operation interface agent: responsible for completing the interaction and cooperation between the satellite health management system and ground operation management, receiving ground control, and reporting health management results. It is generally realized by the telemetry and telecommand functions of satellite.
e. Communication service agent: it is the basis of the health management system. In the satellite integrated electronics system, through the on-board information network, the information interaction channel between different agents is built, the standard communication protocol and mechanism are defined, and the data format of the agent is standardized to ensure that all the information and output results required by the agent work can be correctly and timely transferred.

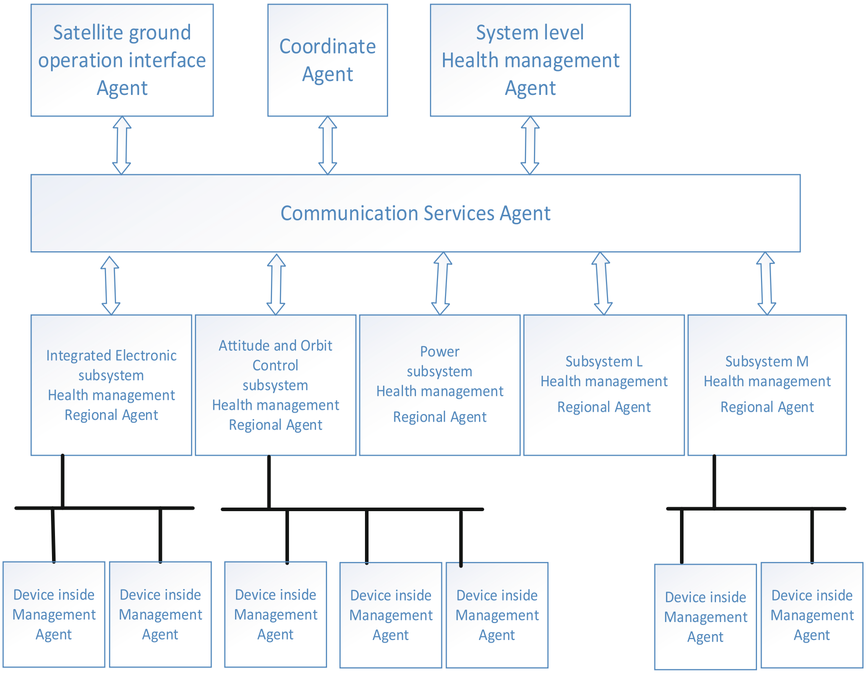

Fig. 2. Framework of satellite health management system based on MAS

The advantage of the above framework scheme is that each regional agent has a certain degree of autonomy, and can choose the most reasonable scheme, algorithm or processing process to achieve regional health management according to the function or design characteristics of its subsystem and stand-alone. The internal composition of the agent is shown in Fig. 3. Its internal algorithm, knowledge base, diagnostic processing and other functional units are designed according to different tasks. For example, a subsystem does not need to predict its life, but only needs fault diagnosis; Some subsystems adopt diagnosis and disposal decisions based on simple rule knowledge, while some systems are difficult to abstract rules, so model-based diagnosis methods may be required. In a word, in the MAS based system, under the constraint of the same external interface and communication specification, the regional agent adopts a similar structure to carry out independent design.

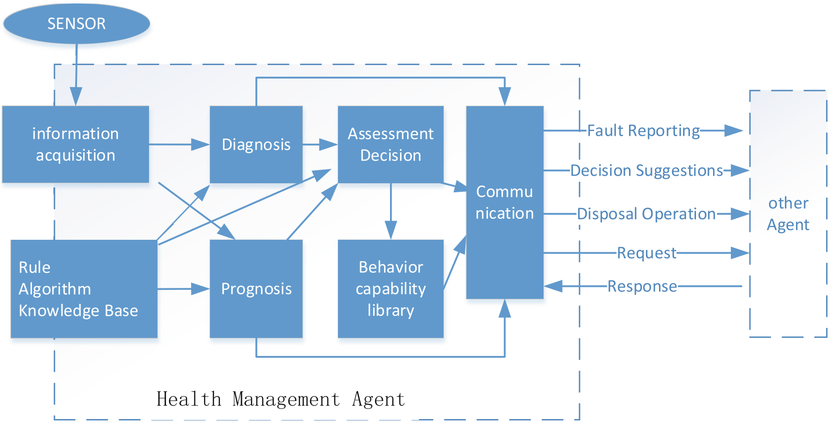

Fig. 3. Internal structure reference of health management agent

5 Implementation Scheme and Key Problem Analysis

5.1 Implementation Scheme

In the satellite engineering design, agents at different levels in the MAS-based satellite health management system architecture are implemented using the following scheme.

a. The integrated electronics subsystem gathers all subsystems and single machine telemetry, commands, etc. The system level agent is implemented in the integrated electronic system to complete the health management of the entire satellite/spacecraft. Since the integrated electronics system of the satellite is responsible for collecting and processing the telemetry signals of the whole satellite, such as temperature, analog quantity, switching value, etc., the status telemetry required by the subsystem level agents to complete fault diagnosis needs to be obtained from the integrated electronics system. At the same time, the monitoring abnormal event reports, diagnostic results, evaluation conclusions, decision-making suggestions, fault handling requests and other information sent by the subsystem level agents also need to be reported to the integrated electronics system in a timely manner.
b. The subsystem level agent is implemented by the intelligent units in each subsystem, such as the Attitude and Orbit Control Subsystem (AOCS), whose control computer can be responsible for the health management of the AOCS itself and the management

of the single machine and components (various sensors, actuators, etc.) in the system. For subsystems with telemetry acquisition capability, the state parameters required for health management are obtained through internal interfaces; Other parameters collected through integrated electronics can be obtained from the integrated electronics system through the satellite internal network. Abnormalities and fault diagnosis results found in the subsystem can be handled by itself or submitted to system level management according to the severity and scope of influence of the fault.

c. For some subsystems without intelligent units, such as Thermal Control subsystem, the integrated electronics system is responsible for monitoring and controlling the state of the heating circuit. In this case, the subsystem level Agent can be implemented by the software of the integrated electronic system as a functional module, and is relatively independent in structure. The external information interaction interface of the software module should follow the interface protocol equivalent to other subsystem level agents, which is conducive to the standardization and extensibility of system design.
d. The implementation of stand-alone agent is similar to that of subsystems. There are also two specific implementation schemes according to the degree of intelligence of different stand-alone. For some simple stand-alone machines or components, their health management can be used as a specific content of subsystem health management, and the agent of their own level can not be set separately.

Figure 4 shows the implementation scheme of the above system architecture.

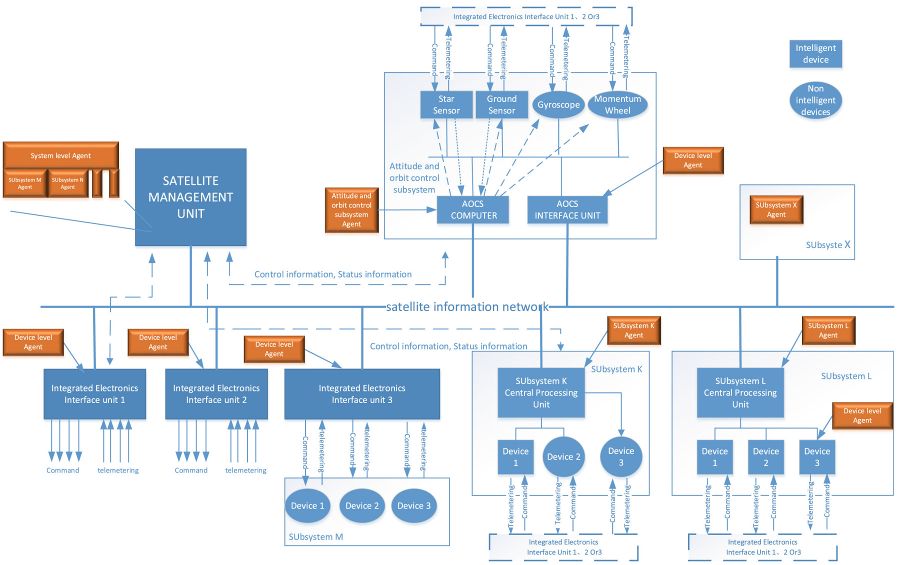

Fig. 4. Implementation Scheme of Satellite Health Management System Architecture

5.2 Analysis of System Characteristics and Key Problems

MAS not only describes the basic capabilities of each agent, but also expresses the structure, function and behavior characteristics of the whole system through agent's communication, cooperation, coordination, management and control. In MAS, the interoperability of agents, the negotiation and cooperation among agents are the key problems to be solved in system design. Compared with the general distributed system, the establishment of intelligent health management system based on MAS in satellite has certain particularity. Although the information system of the intelligent satellite system has certain characteristics of networking, it adopts the integrated electronics system as the center, and realizes the interconnection architecture among different subsystems through the communication network, but it is essentially a hybrid system combining centralized and distributed mainly in the following aspects.

a. For safety and other reasons, most commands of the satellite, especially the power on/off commands of various equipment, are sent by the integrated electronics system, and the control of on-board equipment is often subordinate to the whole satellite system level. The commands issued by each subsystem can only operate some equipment in its area. Therefore, in the design of function agents in each region, because local control cannot cover all functional units in the subsystem, the control commands of some functional units need to be sent to the superior system.
b. Like the command, in order to save hardware overhead, the telemetry status of each device, especially the analog telemetry of voltage, current, temperature, etc., is usually collected by the integrated electronics system, organized and transmitted in the integrated electronics system's software. Therefore, part of the condition monitoring information of the equipment is first collected into the software for processing and downloading. During the operation of health management by the regional agent, the agent cannot obtain all the required observations through local sensor collection, and needs to obtain them from the integrated electronics system.
c. Some subsystems do not have intelligent equipment with management function in the subsystem, and the control and monitoring of the equipment are completed by the integrated electronics system. In this case, the regional agent has no implementation carrier and needs to rely on the integrated electronics system to complete.
d. In order to obtain high reliability, satellite systems usually take a lot of fault tolerance and redundancy design measures. As a result, the satellite system model is complex, and there are many logical branches and cross links. The agent in the health management system will have dynamic access, exit, replacement and other situations, which requires the system to have strong scalability.
e. Compared with the electronic information system on the ground, the network communication bandwidth, computing power, storage capacity and other resources of

the on-board electronic information system are very limited. The implementation of related agents needs to be more concise and efficient.

Based on the above characteristics, to construct a satellite health management system based on MAS, the following key problems need to be solved and the corresponding design and implementation strategies are as follows.

a. The regional division and implementation strategy of agent should be organically combined with the system architecture based on integrated electronics system.
b. The communication system design should realize the information interaction between different agents in the existing system communication architecture to meet the needs of distributed management.
c. The allocation of system control rights can realize the reliable transmission of control information between the lower layer and the upper layer, legitimacy inspection, authority confirmation, etc.
d. Realize the dynamic management of multi-agent, and dynamically realize the access, exit, online, offline and other functions of agent according to the system configuration.
e. Agent implementation and optimization under the condition of limited resources, including optimization of diagnosis and prediction algorithms, sampling or compression of monitoring measurement data, optimization of agent implementation overhead, etc.

6 Conclusion

Intelligentization is an important direction of the development of space technology in the future, and improving the level of intelligent fault diagnosis is one of the important goals. By improving the intelligent autonomous ability of fault management during in-orbit operation and reducing the dependence of satellite operation management on ground and manual, the availability of the system can be greatly improved. In order to meet the requirements of satellite tasks, we conducts research on the architecture and system scheme of the health management system in view of the characteristics of intelligent and networked integrated electronics system in the future. Under the framework of the on-board information system with integrated electronics system as the core, a distributed health management system based on MAS is proposed, and a multi-agent health management system model is given, a feasible solution is proposed for the design of future satellite autonomous health management system. By analyzing the design characteristics of the satellite system, the key problems and implementation strategies of the above health management system are given, which can provide effective reference for the actual satellite engineering design.

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