A Method of On-Board Dynamic Health Management of TT&C Transponder of Spacecraft

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Abstract. A method of on-board dynamic health management for spacecraft TT&C transponder is proposed. The on-board working state of TT&C transponder is a process of dynamic change in a certain and limited range. The CTU belonging to the OBDH subsystem collects the working state of the TT&C transponder in real time, and judges whether the operation of TT&C transponder is normal by judging whether the current state is consistent with the expected state. The CTU software designed the state machine of health state detection of TT&C transponder, established a health management data model, completed the autonomous health detection of TT&C transponder and the autonomous reset operation, and realized the on-board abnormal removal of TT&C transponder.

Keywords: TT&C transponder · Central Terminal Unit (CTU) · Dynamic detection · On-board health management

1 Introduction

With the development of China's space industry, the types and quantity of spacecraft in orbit are increasing day by day, and their life span is getting longer and longer. On-orbit management has entered the stage of multi-spacecraft parallel management [1]. Spacecraft in orbit is an important part of life cycle of spacecraft. Compared with the spacecraft products themselves, users are more concerned about the operation service of spacecraft. Spacecraft in orbit fault diagnosis and processing and in orbit data analysis and reuse technology is particularly important.

The ability of data processing and management of each subsystem by spacecraft onboard computer has been greatly improved, which provides a good foundation of spacecraft autonomous management [2]. The research on spacecraft autonomous health management technology has been continuously deepened, and a relatively systematic design method of autonomous health management system has been formed [3–5]. The TT&C transponder is an important equipment of the TT&C subsystem of the spacecraft. If there is an on-orbit fault, the telemetry and telecommand channels of the spacecraft will be disconnected, thus affecting the normal work of the spacecraft. Statistical data show that the on-orbit failure rate of spacecraft TT&C subsystem reaches 4% [6].

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A common fault removing method is to periodically close and open the TT&C transponder, used to avoid the TT&C transponder working abnormal. This method does not judge whether the TT&C is working abnormal in real time, that is, no matter whether the TT&C transponder is working abnormal, it will be forced to close and then open the transponder. In this way, when the TT&C transponder is working normally, it will also be closed, so there is a risk that the earth station injection instruction will not be properly received during the period from the TT&C transponder is closed to the open.

This paper presents a method for dynamic health detection and recovery of the TT&C transponder. Spacecraft health management system can obtain the health status of the TT&C transponder in real time, and judge whether the TT&C transponder is working abnormally. Once the TT&C transponder is abnormal, it can send fault relief and recovery instructions to make the transponder return to normal.

2 Principle of Fault Detection

2.1 Health State

Finite state machine, which represents a finite number of states and the mathematical model of their transitions and actions, is widely used in computer, communication, digital operation design, software engineering and other fields [7, 8]. Spacecraft and its components will be in a certain state at any time [9], and monitoring and judging the state is an effective fault detection method.

The state changes of a typical TT&C transponder during normal operation include state1, state2 and state3. When the TT&C transponder is working normally, it changes in the order of "State1 → State2 → State3", and the three state parameters change in turn once for a state cycle (called the state cycle of the TT&C transponder), as shown in Fig. 1.

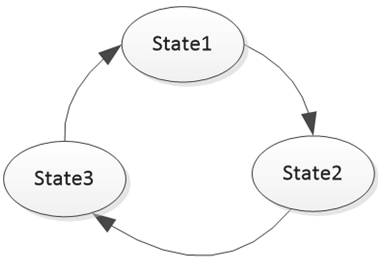

Fig. 1. TT&C transponder state cycle

If the TT&C transponder is always working normally, it will change in the order of "State1 → State2 → State3". If the working state of the TT&C transponder is no longer changing or the order of state change is not "State1 → State2 → State3", it indicates that it is working abnormally.

2.2 Fault Decision

The central terminal unit (CTU) collects the working states of the TT&C transponder periodically (this period is called CTU collection period) and transmits them down through real-time telemetry [10]. The working state of the TT&C transponder changes after CTU collection. Since there are three state parameters in each state cycle of the TT&C transponder, CTU continuous collection for three times (i.e., three collection periods) will complete the collection of one state cycle of the TT&C transponder. Corresponding relationship between CTU collection period and state cycle of the TT&C transponder as shown in Fig. 2.

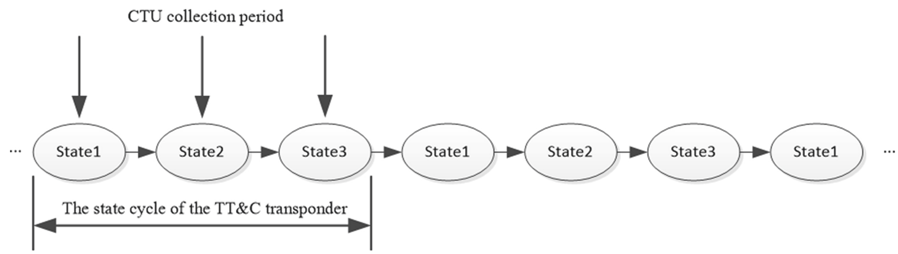

Fig. 2. Relationship between CTU collection period and state cycle of the TT&C transponder

CTU gets its state parameters from the TT&C transponder in each collection period, and then retrieves the working state relation table of the TT&C transponder, as show in Table 1, to determine whether it is the expected state parameters. If not, it indicates that the current state cycle of the TT&C transponder is abnormal. If the TT&C transponder is abnormal for three consecutive state cycles, it is determined that the TT&C transponder is abnormal.

Table 1. Expected state of the TT&C transponder

No.	The current state of the TT&C transponder	The next expected state of the TT&C transponder
1	State1	State2
2	State2	State3
3	State3	State1

If CTU determines that one of the state parameters in the state cycle of the TT&C transponder is not the expected state parameter, indicating that the state cycle is abnormal, then the remaining state parameters in the state cycle will not need to be judged, and will directly wait for the arrival of the next sate cycle to start the judgement again. Assuming that the first expected state parameter in the current state cycle is State1, but the actual state parameter collected by CTU is not state1, it indicates that this state cycle is abnormal. The remaining two state parameters in this state cycle do not need to be judged, and the judgement will be started again after the arrival of the next state cycle, as shown in Fig. 3.

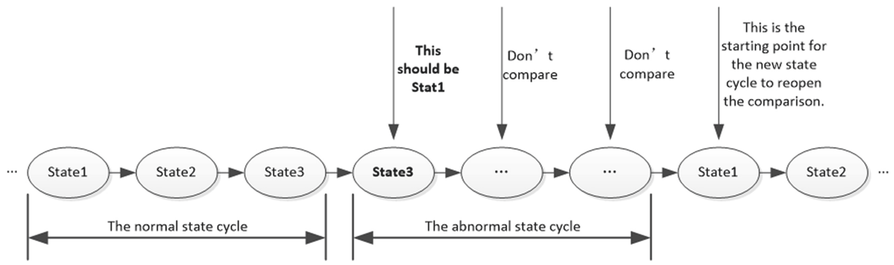

Fig. 3. Example of normal status period and fault status period of T&C transponder

2.3 Fault Removal

After determining that the TT&C transponder is abnormal, CTU will automatically send the reset instruction of the TT&C transponder to reset it, so as to realize the abnormal removal of the TT&C transponder. Because CTU is used to independently complete fault detection and processing on board, it reduces the links of abnormal discovery, fault determination, operation and processing on the ground, so as to realize quick fault removal and improve the reliability of the system quickly and effectively.

3 Design and Application of Health Management System

CTU is the center of spacecraft data interaction and has the advantage of unique data resources. As spacecraft system-level software, CTU software is responsible for spacecraft system-level health management. Based on this, CTU shall automatically remove the abnormality of the TT&C transponder in orbit [11].

3.1 System Composition

The health management system for the TT&C transponder is composed of the TT&C transponder and CTU. The TT&C transponder is the tested object, while CTU is the health detection and execution unit. In CTU, hardware and software jointly complete the health state detection and recovery, as shown in Fig. 4.

The health detection module drives the state acquisition module to complete the collection of the working state of the TT&C transponder within each collection period, and to complete the health judgment of the working state of the TT&C transponder. The health recovery module obtains the health results generated by the health detection module. If abnormal operation of the TT&C transponder is found, the instruction data will be transmitted to the instruction execution module, and the instruction execution module will generate instruction signals according to the instruction data and output them to the TT&C transponder, so as to realize the state recovery of the TT&C transponder.

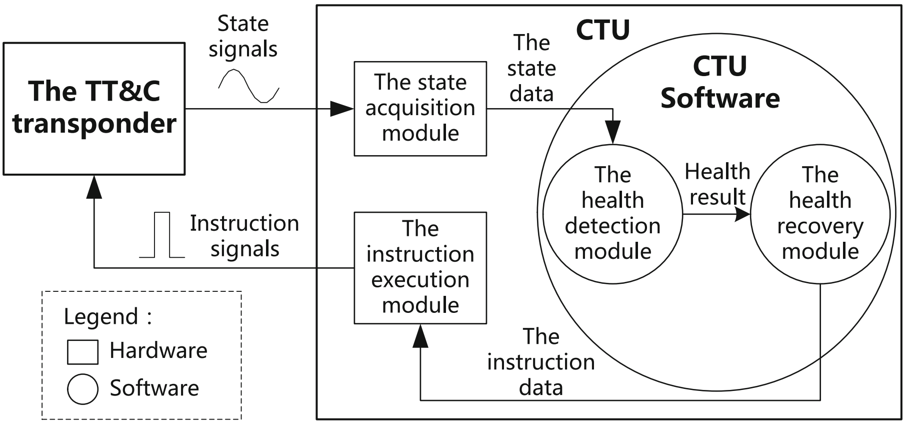

Fig. 4. Health management system composition

3.2 Design of Fault Detection and Recovery Process

With the increasing of software complexity, it is a very practical and effective way to solve software development problems by using abstract means to raise the level of abstraction [12].

The health state detection of the TT&C transponder is a dynamic detection process, that is, CTU needs to detect whether it is abnormal in the process of dynamic state changes of the TT&C transponder, which is different from other health detection process that only need to determine one or more static parameters. Based on this, CTU software designs a state machine to dynamically detect the working state of the TT&C transponder, as shown in Fig. 5.

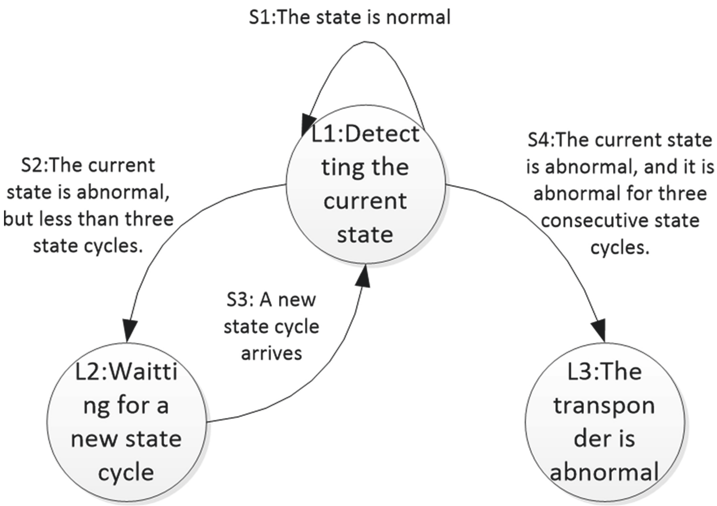

Fig. 5. State transition diagram of health detection

In order to facilitate CTU software to accurately detect the working state of the TT&C transponder, a health detection data model is established. The model elements include:

1) The current states of the TT&C transponder. This state is the state collected by CTU from the TT&C transponder in each collection period.
2) The expected states of the TT&C transponder. CTU collects the current state from the TT&C transponder in each collection period, and then looks up the table to get the expected state of the TT&C transponder.
3) State count. It is used to record the number of states in the state cycle of the TT&C transponder judged by CTU. The state count is 0, 1 and 2, which correspond to one state parameter in the state cycle respectively. When the state count changes to 2, it indicates that the judgment of the current state cycle is completed.
4) Abnormal state cycle count. Used to record the number of continuous abnormal state cycle of the TT&C transponder.
5) Flag of waiting for the new state cycle. Since the TT&C transponder has three state parameters in one state cycle, the remaining state parameters do not need to be judged if the current state cycle is abnormal. When the flag is set to true, wait for the next state cycle to come and start the judgment again.
6) Abnormal flag of the TT&C transponder. If the TT&C transponder is abnormal for three consecutive state cycles, the TT&C transponder should be determined to be abnormal, and the flag should be set as true. CTU will remove the transponder abnormal after detecting this flag (Fig. 6).

Based on the above state transfer and data model, CTU software completes the collection of the state parameters, determination and autonomous removal of abnormal conditions of the TT&C transponder. The specific process is shown in Fig. 7.

3.3 On-Orbit Applications

The health management method proposed in this paper has been applied in many resource survey satellites in China. There was an anomaly in the TT&C transponder of a satellite in an invisible TT&C arc outside China. CTU software detected the anomaly in time and recovered it autonomously, so that the satellite could work normally when it entered the visible arc of the TT&C transponder in China. And the ground station could inject the subsequent payload tasks of the satellite normally, and ensured the continuity of the satellite's work.

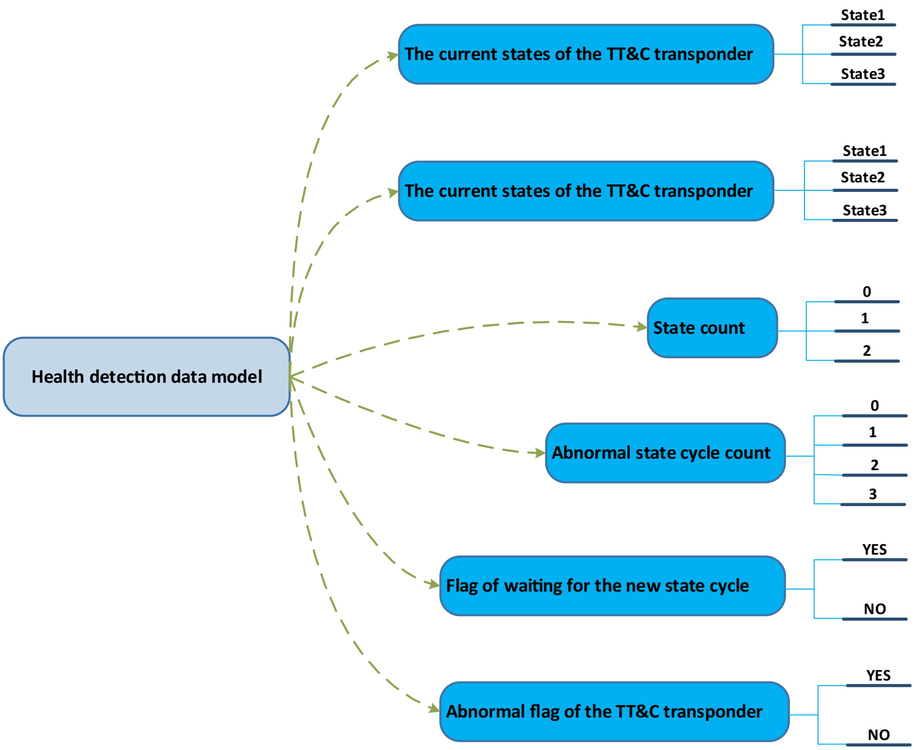

Fig. 6. Data model of health detection

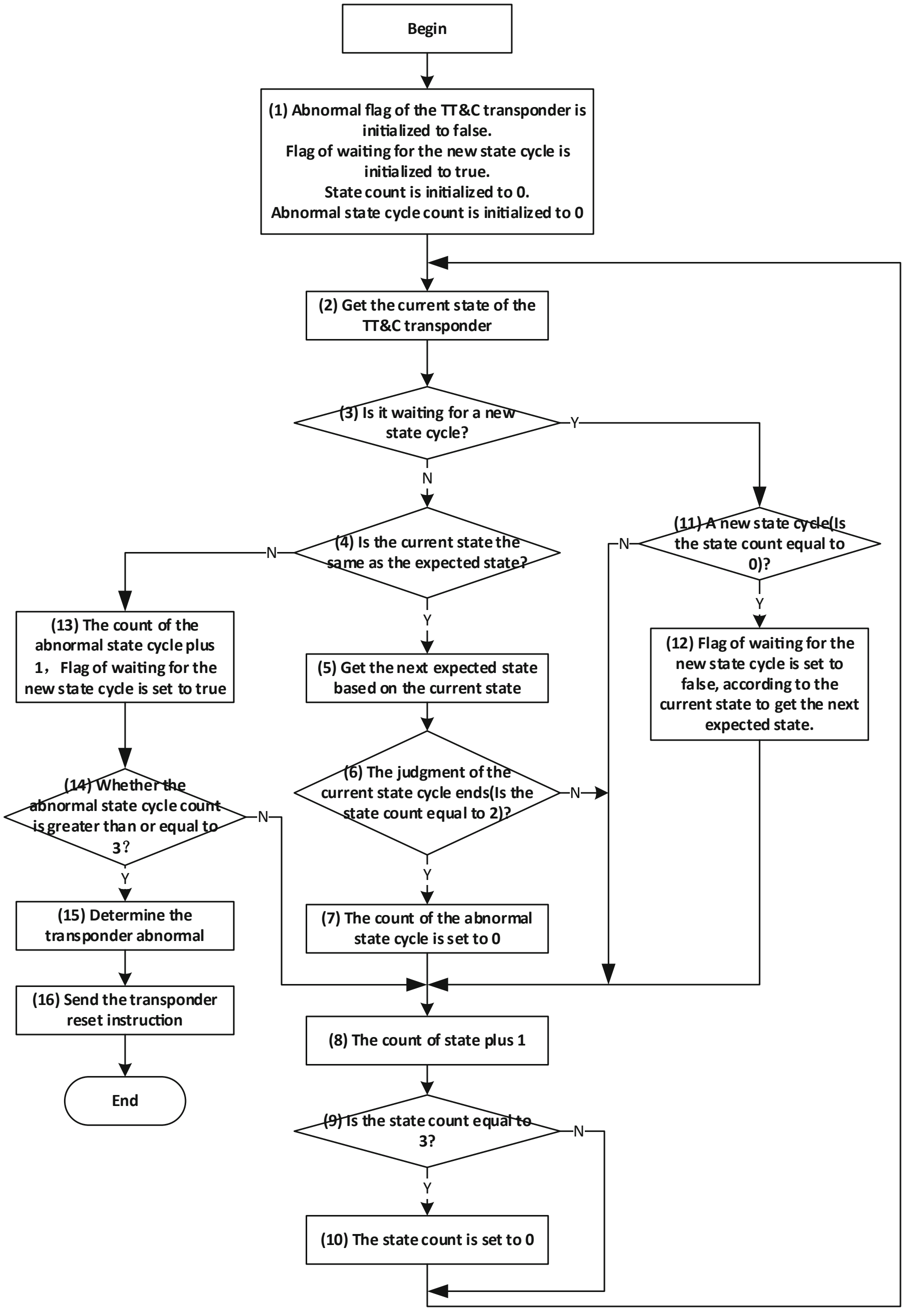

Fig. 7. Flow chart of method relieving T&C transponder fault

4 Conclusion

The on-orbit health management method of the TT&C transponder proposed in this paper is accomplished by CTU. CTU software designed the detection state machine and the health management data model, then CTU software collects the states of the TT&C transponder in real time, so that CTU can accurately and timely determine whether the TT&C transponder is abnormal in orbit, and autonomously reset the TT&C transponder, so that the transponder can be timely restored to the normal working state, to ensure the safety of spacecraft in orbit operation.

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