Satellite Control System Based on Operation Prediction

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In a satellite control center, the real-time control system is a key link for complex mission operations. However, in crucial operations, the existing methods to monitor and judge the procedure are improper to the complex procedures; and it depends heavily on the professional engineers to monitor and estimate the entire process. To deal with this problem, in this paper, we propose an operation-prediction concept, constitute a real-time control system, and design a Satellite Control and Monitor Language (SCML) to describe the prediction. This overall solution can correctly describe the behaviour of the spacecraft during whole control procedure, and provide accurate and quick judgments for the critical operation.

I. Introduction

Real-time judgment is an important part in the satellite-ground control procedure. During the crucial operation phases, the operator must monitor and judge the state of satellite quickly and accurately. On one hand, a false warning will interrupt current operation, which will directly affect the following operations and disturb the whole plan. On the other hand, a neglected warning, as well as a delayed warning, will lead to missing the chance to rescue the satellite from malfunction, which may result in the failure of the mission.

The monitor system is one of main parts in the real-time control system, as shown in Figure 1. The judgment from the monitor system is the base for the following plans and operations. So that the main functions of real-time monitor system are to estimate the behavior quickly and accurately, and to judge the procedure with a proper tolerance.

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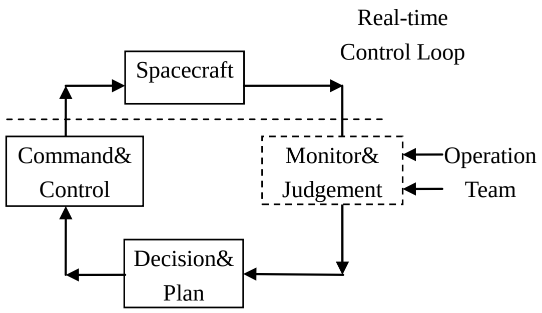

Figure 1. Real Time Control Loop

During crucial operation phases, there are many complex events connected with each other, which would change the spacecraft's work mode, data range, and behavior. However, the current methods of automatic monitor can only carry out some simple judgment under stable states, and they are inappropriate to the dynamic operation and changing telemetry. The operation team members are still relied on heavily to monitor and judge the satellite's behavior. The solutions of real-time judgment are far behind the requirements.

1. Analysis on Current Methods

To monitor the operation procedure effectively, researchers from universities, enterprises and space agencies provided many methods and solutions for real-time operation [1.2.3.4.5.6.7]. In general, there are three main methods applied in practice: manual judgment, command-based judgment, and expert system. However, these methods are still insufficient for the complex real-time operation on satellites.

1.1. Manual Judgment

This is a very basic way to monitor the control procedure, depending on operation team members. On the monitor system, the latest telemetry data are refreshed, and the telemetry curves are shown to record the recent trends. But it is not shown whether the data are coherent to the control procedure. The operators and experts are expected to judge and estimate the spacecraft's activity according to their knowledge and experience [1.3].

This method certainly costs too much manpower, as the crucial operations may last from months in early orbit phase operation to years in the long-run inter-planet exploration.

1.2. Command-based Judgment

This is a way to judge the changing state of satellite after every command. In the command database, there are descriptions which show the changes of certain telemetries corresponding to every command. That is a very basic function in satellite control centers [2.4.5.7]. However, this approach has some limitations.

1) It is difficult to judge some important commands. It is very common that a command is versatile with different parameters in it. As a result, it is hard to conclude whether the command is executed.

2) It is impossible to judge a long procedure. Usually a complex operation could involve a list of combined command. But a simple addition of every command's effect would not be considered as the real purpose of the control.

Although it is a basic ability, command-based judgment method is limited to the command level, and unfit for complex event.

1.3. Expert System

Expert systems based on telemetry and rules are developed in control centers [2.5.6], among which the rule-based expert system is a typical one. It is good at routine procedures in which the satellite works in a stable mode. Nevertheless, there are still some crucial problems in the application of expert system.

1) For an expert system, it is difficult to fully understand the changing state of the satellite, because it is hard to give entirely reasoning logic from hundreds of telemetries to a certain mode.

2) The expert system may not understand the target and the course of the control procedure, and could not distinguish an intended movement from an abnormity.

As a result, expert systems are often limited to calm phase with simple routine operations in a stable mode. It has many difficulties in supporting complex operation in crucial phase.

2. Monitor Concept

In the real-time control system, there are 3 parts as judgment, decision and action, to constitute a control loop. Depending on the judgment methods, we divide the control loops into 2 types: perception loop and prediction loop.

2.1. Perception -based Control Loop

The concept of Perception-based control loop is shown in Figure2. In this loop, the controller could understand the object only by the observation data. First, the data are logically reasoned on the complex rules defined in a knowledge base, so that the satellite's work mode is ascertained. Then all relative telemetry data are compared to the standard range in this work mode, and performance are evaluated. The expert system based on rules is in fact a typical perception-based control mode.

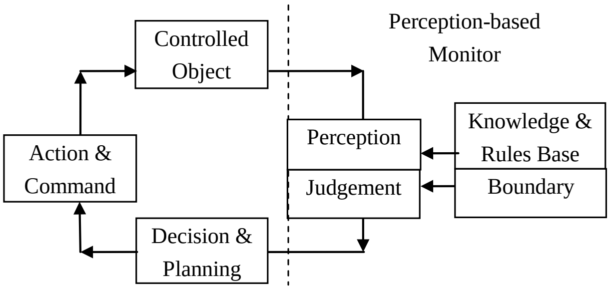

Figure 2. Perception-based control loop

To understand the satellite's working mode, it is essential that the knowledge rules are completely described, and the logical algorithms are computable. However, as the satellite has thousands of telemetry parameters which are closely related to each other, the vast parameters cause uncountable reasoning logic rules from data to modes. Meanwhile, there may be abnormal data which will disturb the reasoning process, and more logic models should be established to diminish the interference. Particularly, the satellite is affected by self-instruction and ground-command, so that it is hard to understand the satellite's movement and goal just from the current data.

Therefore, perception-based control loop is confined to the steady states and routine operations, and it may not be suitable in the crucial mission operations with changing modes and active commands.

2.2. Prediction-based Control Loop

In section 2.1 we introduce the "manual judgment" method, which is in fact a prediction control loop. How does the operation team deal with the "perception" problems?

As the operation team members have planed operational events, they are very clear about every event's objective and process; and the experts from every sub-system are aware of the performance of the character parameters. Observing the real-time data and their paces, comparing them with the predicted patterns in mind, judging with a tolerance, the operation team comes to the conclusion whether the event control procedure is correct. Figure 3 demonstrates the process. The judgment would continue until the end of an event.

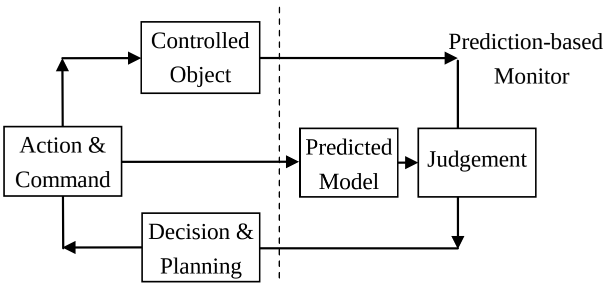

Figure 3. Prediction-based control loop

From above description, we can see that the operators would not mix the data together to “guess” what the satellite is doing now and where it is going. According to the control events list, the operators know what the satellite should do and what the procedure should be like. This prediction mode is more reasonable than the perception loop. So that with the prediction loop, we could get more accurate conclusion with less energy and time.

2.3. Behavior-prediction-based Control Loop

We could apply the prediction concept in the satellite real-time control system, implementing the event-level automatic judgment on the traditional command-level monitor. The figure 4 shows a 2-level, prediction-based control system concept.

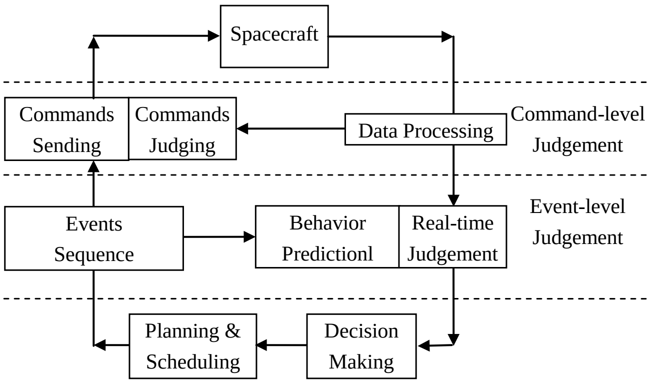

Figure 4. A two-level, prediction-based control system

As the command-level has been used for years, so we focus on the design of event-level. There are two key problems to solve: behavior description and real-time judgment.

3. Behavior Description

3.1. Spacecraft Control and Monitor Language

In order to describe a procedure and assign its goals, we propose a Spacecraft Control and Monitor Language (SCML), which expand the function of Spacecraft Control Language (SCL) from command to monitor. SCL is originally designed by Xi’an Satellite Control Center to program command script, which is widely used in spacecrafts operation.

As shown in figure 5, the light gray part is added to describe the predicted behavior model. In the definition layer, we define simple phrases, which let the users feel easy to program the model of an event. In the implementation layer, the simple phases are realized by other computer language to execute complex functions, and can be modified easily depending on the needs of special spacecraft.

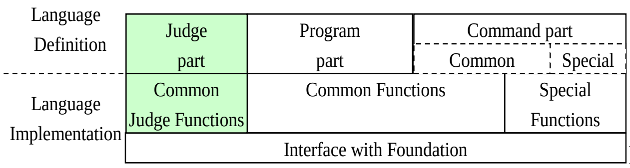

Figure5. Structure of SCML

3.2. Main Facets of SCML

1. Program Part

As a kind of language, the SCML has some general features. Basically, the program part is similar to C language. There are constants and variables, defined as integer, real, string, time and array. The general expressions in SCML include: arithmetic expressions, relation expression and logic expressions. And there are basic statements to organize a script and output a massage.

And the control statements are used to control the running status of a script. They would cause branching, jumping, suspending, waiting, or opening a subroutine when the script is running. This is a feature of a script language. Such statements include: if (…) then… else…, until, goto, wait, pause, etc.

2. Command part

The command part is used to send a command to spacecraft or facilities, which is a key facet of a spacecraft control language. The world-class space agencies implement different command statements. It is the core of an operation script. It has many important functions include:

1) Sending a command to spacecrafts and judging the effect;

2) Sending a packet of data to spacecrafts, such as time-tagged commands or program;

3) Sending a command to control the ground facilities.

3. Judge part

The judge part is a new feature added to the SCML, which distinguishes SCML from other spacecraft control languages. The statement is followed by a variety of restrictions, which will assign a telemetry data, define the constraints, and set a target goal. The format is as follow:

JUDGE telemetry / restriction 1 /… / restriction n

When the script runs into a JUDGE statement, a corresponding function at the implementation layer will be called, which would be responsible for getting the telemetry from buffer, calculating the trend and pace, comparing with criterion and target with restrictions. The result of this judgment statement will be send back to the script.

The judgment statement could make these conclusions on one telemetry data:

1) The state and mode is right.
2) The value is within a proper range.
3) The trend of the change is right, and the pace of the change is reasonable.
4) The deviation of the change is acceptable.

3.3. Monitor Script

To describe the predicted behavior of commanded spacecraft, a control and monitor script, written in SCML, is programmed to define the whole procedure of the event.

More than using the judge statement to check a single telemetry, the script could assign a logical expression of many telemetry parameters and compare the results with the expectation. Also it can control the time and sequence of the script according to the event's steps by the use of basic elements of SCML.

The monitor script has following functions:

1) To assign the goals and the stages of an event.
2) To pick out key parameters and check their states.
3) To define the logical relations among parameters and calculate them.
4) To set timers and keep the schedule, and control the pace of the script.
5) To judge the correctness of the process and output the judgment continuously.
6) To detect the abnormal parameters and output them with a reason.

4. Real-time Judgement

To judge the procedure in time, we present a monitor system framework based on the prediction loop and behavior description.

4.1. Goals and Functions

The main tasks of the real-time monitor system are to monitor the spacecraft's activities during complex events, to judge the correctness of the procedure automatically in real time, reducing the dependence on operation team. The monitor system should give not only the conclusion but also the main proofs, such as primary telemetry data, and the difference between prediction and reality, to help the operators re-evaluate the procedure.

According to the timeline, the real-time monitor system should provide the planners and operators these judgements:

1) At the beginning of the event, the comprehensive pre-conditions should be met to start an event.
2) During the action, the performance of the spacecraft should be kept in a correct sub-mode and reasonable trend and pace.
3) At last, the spacecraft should go to the target mode and be kept stable as expectation.
The behavior-prediction based monitoring system consists of 3 components:
1) An script control interface to monitor and control the monitor script based on behavior prediction;
2) A platform to compile and execute the script;
3) A graphic user interface (GUI) to show results and main proofs.

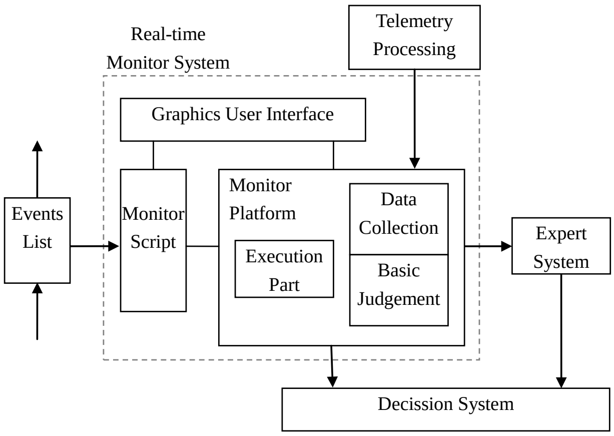

Figure 6. The Real-time Monitor System

4.2. Script control interface

The script control interface is where the operators control the monitor script written in SCML, which describe the behavior prediction of the spacecraft. The operators could not only observe the running status of the script and those important data in the script, but also manipulate the script from this interface.
The monitor script and language are introduced in section 4.

4.3. Platform

The monitor platform undertakes the most basic tasks to support the script and GUI. It comprises 3 parts: execution part, data collection, and basic judgment.
1. Execution part
This component is used to support SCML, to compile, link and execute the monitor script. Moreover it could support the operator to control the script in real-time, as well as running the script automatically.
2. Data collection
This component is used to acquire and maintain the data related to the control process, such as picking out processed parameters, collecting and buffering real-time telemetry.
3. Basic judgment
This component is a special function in the monitor platform, and it is called by the script by judge statement. In accordance with the assigned parameters, which describe goals and criterion, this component calculates the recent data and sends a conclusion to the script.

4.4. GUI

Graphic user interface (GUI) is to present results and main proofs by telemetry curve pages. The telemetry curve pages record the recent data, and reveal the state and trend very well. To focus on the event procedure, there are two types of pages according to the necessity and stage:
1) Fixed parameter page. It tracks and records the key telemetries used in the monitor script. At the same time, it records the continuous judgment given by the script. It is an effective way to show the result and its supportive data.

2) Dynamic parameter page. It tracks those “hot” telemetries used as indication of a command’s effect just around the time when the command is executed. The record would begin before the command is send, and end after the command for a while.

Combining long-term key parameters with current important telemetries, the GUI lets the operation team to know the overall and hotspot telemetries at a glance.

5. Conclusion

For complex mission operation in crucial phase, a behavior-prediction based real-time monitor system is discussed in this paper. This solution has the following advantages.

The behavior-prediction based control loop indicates a new real-time control concept, which gives the monitor system enough information to understand the spacecraft’s actions. The SCML-based monitor script could describe the behavior of a controlled spacecraft in corresponding with control events. The monitor system frame could provide an accurate judgment and a friendly interface.

This method is an effective solution to monitor & control the spacecraft during complex operations, and detect any abnormity in real time. It could be widely used in the areas of intelligent objects control, such as robots and spacecrafts.

Reference

[1] Laura Boltz and John Andrusyszyn, “Human Factors Engineering in System Design for Operationally Responsive Ground Systems”，GSAW2008 Conference, Redondo Beach, California, March 31-April 3, 2008

[2] Gonzalo Garcia, “Use of Python as a Satellite Operations and Testing Automation Language”, GSAW2008 Conference, Redondo Beach, California, March 31-April 3, 2008

[3] Jorge Fauste and José Barreto, “An interactive telemetry data analysis tool”, SpaceOps 2006 Conference, Rome, Italy, June 19-23, 2006

[4] Geraldine Chaudhri, Jim Cater and Brad Kizzort, “A Model for A Spacecraft Operations Language”, SpaceOps 2006 Conference, Rome, Italy, June 19-23, 2006

[5] Wolfgang Heinen, “Smart-1 Ground Operations Automation”, SpaceOps 2006 Conference, Rome, Italy, June 19-23, 2006

[6] Ivan Dankiewicz, Simon Reid and Allan Pascoe, “Learning From The Experience Of Spacecraft Operations Automation”, SpaceOps 2006 Conference, Rome, Italy, June 19-23, 2006

[7] D.M. Cruickshank, A.J. Aparicio, A.A. Mistry and B.R. Poynton, “Using ARES to Improve Efficiency in Satellite Operations”, SpaceOps 2004 Conference, Montreal, Canada ,17-21 May 2004