Measurement and Control Event Planning for Formation Satellites

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Abstract. Formation satellites have configuration requirement. It takes new problem to the automatic process of long term satellite management. Because formation satellites can be managed by inter satellite links for TT&C missions. The complex restricted conditions have been analyzed, including that the execution time and content of TT&C event are various, and time is short for TT&C and so on. A solution of TT&C mission planning is given for formation satellites with multiple constraints. Based on automatic process for multi-satellite management, the formation satellites can be managed automatically for long term. It is applied in the system for satellite long term management. The result shows that can avoid mistakes caused by manual operation, and improve management efficiency for formation satellites.

1. Introduction

Since satellites in their orbits, the ground TT&C system and application systems must carry out management operation in long term, such as continuous measurement, monitoring, control and so on. Formation satellite is different from the traditional low orbit satellite system. Satellites formation flying can decompose the complex system by a certain space. So the functions can be completed by several relatively simple systems. Then those relatively simple systems can constitute a complex and powerful system virtually. It should share information among satellites by inter-satellite link, satisfy formation requirements, and collaborate to complete tasks. For low orbit formation satellites, the long term management mission is different from normal low orbit satellites because of its orbit characteristics and configuration requirements. Arrangement TT&C events for long term management involves more restraining factors, and the telecontrol has higher operational complexity. So it brought new problems to automatic process of long term management. And problems mainly lie in TT&C mission planning part. Thus according to that process mentioned above, that arrange management events and its execution flow is the key problem should be resolved to formation satellite management for long term.

2. Assumption

If there are m numbers of formation satellites, define a satellite set named \( S = \{S_1, S_2, ..., S_m\} \). For one satellite named \( S_i, 1 \leq i \leq m \), there are k number of events, \( k \geq 1 \). Define the management event set named \( E_i = \{E_{i,1}, E_{i,2}, ..., E_{i,k}\} \). For one event named \( E_{i,j}, 1 \leq i \leq m, 1 \leq j \leq k \), there are p number of constraints. Define the dependent constraints set named \( R_{i,j} = \{R_{i,j,1}, R_{i,j,2}, ..., R_{i,j,p}\} \), \( p \geq 1 \). For formation satellite, there may be correlation constraints with inter-satellite links. There are q number of correlation constraints assumed, and it would be named \( R_{i,j}^c = ... \).
\{R_{i,1}', R_{i,2}', ... , R_{i,q}'\}, \quad q \geq 1, \quad R' = \{R_i'\}. By the long-term management process, event planning means that analyze the management requirement of formation satellite, then construct sets mentioned above, and arrange the execution sequence, time or injection serial number of uplink data, according the satellites tracking planning.

### 3. Satellite Management Automation

With development of space cause, the satellite amount in orbit is increasing. So it is a heavy task to management in long term. Management in long term is not just to monitor satellites normally. It have to take healthy checking for every satellite, fault diagnosis and so no. So there are too many events. And the management task is becoming more difficult. To satisfy the demand of satellite management in long term with great amount, high requirements and difficulty, satellite management model has been changed to new constructure of great center and small station, and the system of management in long term has capability of automaticalrunning[1]. As illustrated in Fig. 1, the planning dispatch system of satellite TT&C is controller to manage each of the subsystem running automatically, such as TT&C foundation software, equipment telecontrol platform, satellite fault diagnosis system, satellite telecontrol platform, state comprehensive display system, and so on. Then the equipment platform control equipments in stationremotely and coordinate with telecontrol platform calling telecontrol procedure based on SCL[2] （Spacecraft Control Language） to inject uplink data automatically. Therefore, that fills the need of management satellite, simplify the manual operation, and avoid risk caused by manual operation scientifically.

The satellite management automatic procedure could support that managementmultiple satellites in parallel and full time. But the procedure is based on single satellite management. For formation satellites with inter satellite links, they are coordinated to conduct the task. The planning arrangement is different from single satellite. But the planning is the input of planning dispatch platform which is the key link of satellite management automatic procedure. So based the satellite management automatic procedure, aim at the character of formation satellite, the event planning could be arranged automatically by analyzing the TT&C events which can be used by TT&C planning node to achieve automatic management for formation satellites.

Satellite event planning could be considered as SRS(Satellite Range Scheduling), it means that arrange resource with time window and other restraints. The research of SRS problem is focused on models and algorithms[3],[4]. They are complex and low efficiency for automatic procedure of satellite management in long term. It is better to design an algorithm based on the automatic procedure and mission requirements of satellite management in long term.

Fig.1. Satellite management automatic procedure
4. TT&C Event and Model Analysis

4.1. TT&C Event Analysis

In long term management phases, the ground control center should manage both satellite platform and load by regulation including orbit injection firstly, when satellites need to calculate the orbit or flight attitude based on ground orbit elements, the ground control center should inject the result of orbit determination periodically. The second one is orbit prediction. According to the given orbital elements, it should accomplish information prediction, such as satellite orbit, sub-satellite point, ground tracking stations, and so on. The third one is orbit or station keeping. Depending on the mission requirements, it should control the satellite orbit or attitude regulating. The fourth one is planning injection. It should control satellite platform or payload to open or shut the responder, data transmission and so on. The last one is remote control command sending. The ground control center should send direct or indirect command to control the satellite actuators to complete conditions setting. So the corresponding key events include orbit data injection, satellite responder switch time setting, payload switch time management, satellite clock calibration, command chain for passing in and out of the station, etc. The TT&C events of management in long term for low earth orbit satellite have been analyzed involving the automatic management process of long term management. The key events and restraints could be represented by table1. Adopting policy of divide and rule, the events could be divided into orbit events and normal management events. The last one has simple relative constraints. Therefore, it is necessary to consider the constraints of orbital events, which having associating constraints not only involves events and also involves satellites.

Table 1. The key TT&C events and constraints

| Description                          | Label   | Period | Start Time | End Time | Event Constraints rE | Satellites Constr- | Number n |
|--------------------------------------|---------|--------|------------|----------|----------------------|--------------------|----------|
| Orbital Parameter Calculating        | E₁      | P₁     | Given Value|          | Given Value          | Null               | Null     |
| Orbital Data Processing              | E₂      | P₂     | Point After E₁ Completed | Null     | E₁                  | Null               | Null     |
| Orbit Injection                      | E₃      | P₃     | Null       |          | Null                | E₂                | Satellites Related | Null     |
| TLE Calculating                      | E₄      | P₄     | Null       |          | Null                | Null               | Null     |
| TLE Processing                       | E₅      | P₅     | Point After E₄ Completed | Null     | E₄                  | Null               | Null     |
| TLE Injection                        | E₆      | P₆     | Null       |          | Null                | E₅                | Null     |
| Relay Satellite Orbit Prediction     | E₇      | P₇     | Null       |          | Null                | Null               | Null     |
| Management Data Injection            | E₈      | P₈     | Given Value|          | Null                | Null               | Null     |
| Uplink Data Block Injection          | E₉      | P₉     | Null       |          | Null                | Null               | Null     |
| Telecommand                          | E₁₀     | P₁₀    | Null       |          | Null                | Null               | Null     |

Analysis the table above, it is apparently that each event has a given execution cycle in long term of formation satellite management. The requirement of automatic scheduling is that arrange execution time and sequence conforms to all of the constraint conditions according to the execution cycle, then the automatic scheduling system calls each subsystem or subprocess running corresponding to each event, at the end it could realize management formation satellites.
4.2. TT&C Model Analysis

The TT&C model of formation satellite depends on the communication and information exchanging model. Now the formation satellites mainly adopt communication model of master and sub. It means that there is one satellite takes the role of master naming S1 supposed, and others are sub satellites. As illustrated in Fig. 2, there are communication link between master and sub satellite, but there isn’t communication link among sub satellites. Therefore, if there is a satellite without tracking station, it could controlled by master satellite make use of the link between them. There are \( \sum_{i=0}^{m-1} c_{m-1} \) kind of TT&C model according to communication models. On the basis of TT&C model, the telecontrolled operation could be made which is a program file based on SCL accord with the requirement of satellite telecontrolled uplink and could be scheduled to run by the automatic procedure for satellite management in long term.

![Fig.2. The communication model of formation satellites](image)

5. Schedule Program of TT&C Events

5.1. Schedule Program

Based on the above analysis, the TT&C events scheduling program of formation satellites involves four stages, which include net plan analysis, constraint analysis, TT&C model analysis and event scheduling, as illustrated in Fig. 3. The primary job of first stage is to analyze the ground stations and relay satellites tracking information related to formation satellites, and then obtain TT&C windows condition. The second is to acquire TT&C model based on the tracking plan, and then obtain telecontrol operation. The third is to search tracking windows meeting the condition of constraint after analysis the constraint set of TT&C events. The relationship constraints just involve orbital events. So the main job is to deal with orbital events. The last stage is to arrange the execution sequence of TT&C events for formation satellites and resolve conflict. At the end, it adopts time-triggered mode to execute events, and then automatically schedule corresponding subsystem to fulfill the function stated by related events.
5.2. Application Case

There is a type of formation satellites including two group of satellites. Each group includes three satellites with one master satellite labeled S1 and two sub satellites labeled S2 and S3. According to the requirements of satellite management in long term, it could obtain the input parameters described in table 1, and program based on the arrangement scheme as mentioned above. The most complex event is orbital event labeled E3. Its arrangement procedure could be described as following.

Step 1, Initialize formation satellite set S={S1, S2, S3} , event period Pi, compare object dateCompare is the start date of Pi, the injection label of event Ei is False named isUpload.

Step 2, Obtain the orbital numbers W={W1, W2, W3} planned to tracking based net planning of satellites set S1.

Step 3, If the tracking date of one orbital number equals to dateCompare and isUpload is false for event Ei, then search the search the earliest tracking time.

If isUpload equals to true, the set as False. Otherwise, it should check whether there is same orbital numbers among W2 and W3. If the same one exist in W2, and then set timeStart as the earliest tracking time of S1 and S2, and set mode as 1.

If the same one exist in W3 and then set timeStart as the earliest tracking time of S1 and S3, and set mode as 2. If the same one exist in both W2 and W3, and then set timeStart as the earliest tracking time of S, and set mode as 3. If there isn't same one, and then set timeStart as the earliest tracking time of S1, and set mode as 4.

Step 4 Obtain orbital number and time to inject data or command.

Step4.1 The tracking date equals to execution date.

If the timeStart is between sT and eT of P1, and the execution time earlier than eT, and than set upLoadTime as the point earlier than timeStart by a given period of time1. If timeStart is later than eT and the execution time is earlier than sT, and than set upLoadTime as time2 given between sT and eT. But if the execution time between sT and eT, and then set upLoadTime as time3 given after the execution time.

Step4.2 The tracking date after the execution date.

If timeStart is between sT and eT, and then set upLoadTime as time1.
If timeStart is later than eT, and then set upLoadTime as time2.

Step 5: For satellite S1, it could set the injection number as current orbital number labeled windowID. Then if there is faults with inter-satellite link for S2 or S3, and then set the injection number as the first one among W2 or W3 which is bigger than windowed. At the end, it should set isUploas as true.

6. Conclusion
According to the requirements of formation satellite management in long term, after analysis the TT&C event type and constraints, the TT&C events scheduling scheme is given for formation satellite with complex constraints. On the basis of current automatic management process in long term, the scheme was programmed to applicate in the formation satellite management in long term. In three years of practical application, the scheme has been tested and the result shows that it could improve the degree of automatization of formation satellite management.

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