POLISH MARITIME RESEARCH Special Issue 2016 S1 (91) 2016 Vol. 23; pp. 59-70
10.1515/pomr-2016-0047

AUTO MISSION PLANNING SYSTEM DESIGN FOR IMAGING SATELLITES AND ITS APPLICATIONS IN ENVIRONMENTAL FIELD

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ABSTRACT

Satellite hardware has reached a level of development that enables imaging satellites to realize applications in the area of meteorology and environmental monitoring. As the requirements in terms of feasibility and the actual profit achieved by satellite applications increase, we need to comprehensively consider the actual status, constraints, unpredictable information, and complicated requirements. The management of this complex information and the allocation of satellite resources to realize image acquisition have become essential for enhancing the efficiency of satellite instrumentation. In view of this, we designed a satellite auto mission planning system, which includes two sub-systems: the imaging satellite itself and the ground base, and these systems would then collaborate to process complicated missions: the satellite mainly focuses on mission planning and functions according to actual parameters, whereas the ground base provides auxiliary information, management, and control. Based on the requirements analysis, we have devised the application scenarios, main module, and key techniques. Comparison of the simulation results of the system, confirmed the feasibility and optimization efficiency of the system framework, which also stimulates new thinking for the method of monitoring environment and design of mission planning systems.

Keywords: systems engineering, imaging satellite, meteorological monitoring, space-ground integration

INTRODUCTION

Half a century ago, the Union of Soviet Socialist Republics (USSR) successfully launched the first artificial earth satellite (AES) in the world, which represents the coming era of human exploration and utilization of space resources to serve human productivity and life. According to statistics, China have launched 139 on-orbit satellites until 2014, and this quantity ranks second only to the United States. As an important branch of the satellite family, imaging satellites have found application in major activities such as finding earth resources, meteorological and geological disasters relief support, and supporting agricultural activities. However, the increase in the quantity of satellites and the improving hardware level has led people's expectations in terms of devices relying on satellite to increase. At the same time, there has been a realization that traditional ground-planning systems and mission planning techniques and instrumentation of imaging satellites need to improve.

A traditional imaging satellite is only a command executor in an application process; for example, the Earth observation system (EOS) as shown in Fig. 1. The user delivers the satellite image request to the task-dispatching center according to different work requirements, and after rearranging all user requests the dispatching center standardizes complicated user requests before generating the mission planning scheme and sending the scheme to both the monitoring center and ground station. The monitoring center then compiles the satellite action code and uploads it to the satellite. In addition, they also monitor the satellite status information, such as information relating to the position and satellite sources, and they load the working conditions. The ground station adjusts the antenna to receive data at a specified time according to the plan.

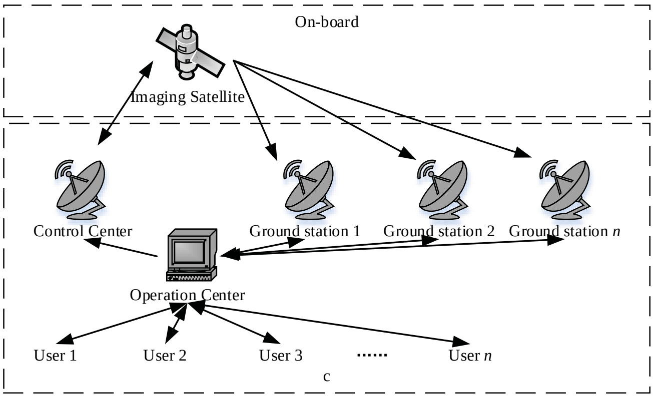


Fig. 1. Earth observation system (EOS) of traditional imaging satellite

Therefore, it is obvious that the mission planning for a traditional imaging satellite involves a process of off-line scheduling with simple loading data, a time during which the satellite cannot acquire working information and guide decisions4. As the satellite hardware level continues to improve, users also demand enhanced image quality and response speed of an imaging satellite. Moreover, the development of image processing and pattern recognition techniques has enabled satellites to perceive image characteristics and support mission planning.

In the face of increasingly complicated imaging demands, the trend is for future imaging satellites to use multi-satellite united imaging to fulfill complicated missions. The mission-planning model for traditional imaging satellites is unable to satisfy the fast-response demand, and cannot overcome the limitations of existing monitoring ability. In addition, because of its low monitoring efficiency in terms of the planning scheme, it is unable to function effectively in the complicated and complex space environment, which means that the traditional mission-planning model is unable to adapt to future imaging instrumentation. As a result, the auto mission planning system emerges in response to the needs of times.

The new type of imaging satellite has the following characteristics: high-resolution ratio, high agility, multi-sensor and satellite data processing and decision abilities, all of which present a new challenge to satellite mission planning: an expanded question range, greater decision variety and constraints, more complex object function, etc. A mission planning system is quite similar to the „brain" of a satellite because it needs to co-ordinate all satellite resources and its intelligence needs the support of each commonly developed module, such as satellite image processing, pattern recognition, and parameter adaptive technology. With the support of these other technologies, the "brain" can make accurate judgments and decisions so as to improve overall system reliability. How to fully apply information acquired by the satellite and planning auto mission tasks so as to enhance the actual profit of the satellite mission-dispatching scheme has become a major research challenge for all space system researchers.

The design goal for a satellite auto mission planning system is to enable the satellite to acquire the environment and status automatically, and to enable it to generate a scientific scheme to improve the utilization rate of satellite resources. Many organizations and scholars are currently studying satellite autonomous management controlling techniques, such as that designed by Chien in the form of an order for EO-1 named CASPER, which can accept instructions based on an actual situation. He also proposed an iterative repair algorithm capable of adjusting the mission-planning scheme according to the changing targets and constraints. The Verification of Autonomous Mission planning Onboard a Spacecraft (VAMOS) project proposed by the German Aerospace Center (DRL) can realize satellite resources automation inspection and adjustment; it can also realize the re-planning based on actual resources usage and task demand generated autonomously by the satellite. The experiment named "Autonomy Generic Architecture: Test and Applications (AGATA)" is projected by the Centre National d'Etudes Spatiales (CNES), and it is a kind of general system architecture demonstration and verification platform that supports spacecraft in comprehensive capabilities such as planning, monitoring, and diagnosing and is still in the testing period. Beaumet has designed a satellite mission planning system and it is also applied to the Pleiades satellite, a French technology experiment satellite. This system is mainly based on the real-time state of the satellite and environmental information with the aim of proposing satellite action for decision-making and to choose a strategy for each action at any time, based on a greedy algorithm of random iteration as its core. The different loads carried by each satellite and the need to realize different functions require the design of special planning processes and algorithms. These systems need to be designed with certain intelligence, yet each satellite functions independently and has different standards, which is not conducive to completing complex task observation quickly and reliablyc.

In this paper, the satellite mission planning system applies to image satellites with different loads, different capabilities, and different orbits. Reorganization of the functions and correlation of different modules enables the key technology for all modules to be abstracted. Finally, the feasibility of this system was confirmed by performing a case analysis for a typical application scenario, which shows the advantages of autonomous planning in future satellite instrumentation.

HOLISTIC DESIGN

SYSTEMATIC OBJECTIVES

The process shown in Fig. 1 allows us to easily establish the characteristics and limits of traditional satellite mission-planning systems. It is these reasons that lead to the difficulties in applying imaging satellite to the environment area. Reasons as follow:

(1) Off-line planning and controlling (dispatching). Currently, it is difficult for imaging satellites to realize real-time

communication with the ground station; this means the ground station can only plan once according to predicted information. This causes conflicting or contradictory problems, such as hardware control or practical constraints, while the satellite is carrying out instructions, which reduces the efficiency of the satellite.

(2) Low information utilization ratio. Real-time information about the satellite can eliminate uncertainty and would be convenient for satellite mission scheduling and controlling. Traditional imaging satellites carry a single load; thus, it uses little information. Satellite mission scheduling has complicated constraints; for example, the imaging effect for an optical imaging satellite is affected by clouds, fog, and haze, and if we do not analyze and respond to this information, the imaging results may be useless.

(3) Decision making is negatively affected. In the traditional satellite mission planning process, the planning is finished at the ground station, and the satellite only accepts executive instructions after simple data processing, after which the results are transferred to the ground station for decision-making. This lowers the speed at which the satellite responds to tasks, which means that important and emergency tasks are affected.

Generally speaking, the performance of the traditional imaging satellite is satisfactory in terms of producing useful information from the perspective of space, but with low efficiency. In view of the above limitations, this thesis proposes design objectives for a new imaging satellite auto mission planning system as follows:

(1) Realize autonomous information acquisition and re-organization for satellites.

(2) Realize autonomous mission scheduling and decision making for satellites.

(3) Realize real-time tasks re-scheduling for satellites.

FUNCTIONAL REQUIREMENTS

Combined with the new operational requirements for satellites and considering that satellite users have different requirements for different missions, we propose the following functional requirements for new imaging satellites:

(1) The capability to autonomously acquire dynamically changing and uncertain information and the ability to effectively process information accordingly. A satellite mission planning process is noted for uncertainties, such as demands that change dynamically, constraints, judgment, and uncertainties in the environment and the availability of resources. The satellite requires the ability to respond to these factors to ensure optimal results under any circumstances and in any environment.

(2) The capability for fast data processing. Satellite mission planning is a complicated process and is highly demanding in terms of temporal efficiency. This would require us to raise the system calculation and processing ability depending on the hardware capabilities. Thus, we need to design the scheduling algorithms reasonably to improve the convergence rate of results and to ensure that a feasible solution is obtained in an acceptable period of time.

(3) The capability to analyze satellite observation results. Increasingly complicated satellite missions make it difficult to process many users' requirements by simply splitting a single imaging task. Each task requires multi-stage decision-making in which decisions in the second stage are based on the results of the previous stage. Therefore, satellites require the ability to process results to allow the plan to be adjusted according to the results obtained in the previous step.

TYPICAL APPLICATION SCENARIOS

The traditional satellite operational process involves splitting complicated tasks into several single images with certain coordinates. New imaging satellites have to satisfy higher-level demands with the following typical applications.

IDENTIFYING TARGET CHARACTERISTICS

Application objective: to acquire target characteristic information as much as possible to improve the success rate of identifying the object. In this application scenario, task completion time can be seen as a common constraint to guarantee the effectiveness of the information.

General procedure: When one target is defined as the most important, the mission-planning system dispatches satellites to finish multi-observations in different directions for a period of time until all characteristics to be acquired can be successfully obtained by the satellite and we have high assurance that the attributes for these characteristics have been identified.

Typical scenario: Some region is threatened by geological disaster; however, the government cannot effectively control it because of limited access to the stricken area. Decisions are required in terms of arranging rescue, estimating losses, and further controlling the disaster situation by comprehensively considering multi-dimensional information such as the nature of the hazard, topographic conditions, vegetation conditions, land use situation, current weather conditions, and the density of the population. However, due to the restricting conditions in all respects, it is more effective to use a satellite to acquire this information. This requires reasonable scheduling and dispatching of satellite resources so as to accomplish tasks effectively and timeously.

SEARCHING FOR AN UNCERTAIN TARGET

Application objective: to locate eligible targets as much as possible in the stipulated time.

General procedure: First, define the area within which the target exists, and then search its terrain by specifying target characteristics according to the information programming search strategy.

Typical scenario: Forest fire is one of a costly natural hazard, and it really spawned a great number of economic loss each year. Government is devoted to monitoring forest fire in a region and hopes to find it and control them effectively. Because the use of alternative methods is ruled out due to limitations in terms of cost and technology, an imaging satellite is the best tool to conduct target searching in this region in a short period of time. A satellite is characterized by a high target recognition rate, wide coverage, and a unique perspective, it can perform general searching in the specified region and find the possible target, and then checking and confirming one by one until all targets are finally found.

TRACKING A MOVING TARGET

Application objective: continuously tracking the target from beginning to end.

Working procedure: The satellite defines the starting point for one target, and then predicts the target location in the next phase and performs continuous observation and tracking. During the tracking process, the satellite adjusts the parameters according to the actual target location and predicted location to ensure the target is always in the detected area.

Typical Scenario: In a sparsely populated area, a serious mobile pollution source is moving. The officer obtained the current position for the source through other means and now they need it to be continuously tracked for final capture. The satellite starts from the current location of the source and forecasts the possible location for the next step and adjusts the observation angle. In this process, the satellite may face many different situations, for example, there might be a large difference between the predicted direction/speed and reality; it may also encounter disruptions such as target loss, or a false target. This requires us to be fully prepared to overcome the changing conditions.

CHARACTERISTICS

The load carried by image satellites is constantly being upgraded, as is its imaging capability. A non-agile satellite would not be able to finish acquiring the image of a river course that is not parallel to the satellite orbit, whereas an agile satellite would be able to do so The following new requirements in mission planning and scheduling are proposed for these new satellites:

(1) Diversity in mission demand. Traditional mission planning systems preset a profit through analyzing the completion of each mission, and determine the planning system according to the total profit. Traditional planning systems simplify a mission as a point with a single imaging model and mission demand, which means that a plan with a high profit target may not reasonable. New imaging satellites need to comprehensively consider the requirements of different users such as time-effectiveness and image resolution.

(2) Changes in the environment influence different tasks in different ways33. Because of the diversity in imaging demands, the influence of the environment on different tasks is not exactly the same, and the constraints for each task can also change accordingly. For example, given the following two tasks, one of which is to acquire the outline of some architecture, whereas the other is to acquire the color of this architecture. When using an imaging satellite to analyze the image, the degree of difficulty is apparently not the same under different weather conditions.

(3) Higher requirement in mission planning time effectiveness. Traditional mission planning usually takes much more time due to the communication links. The timeliness of information directly affects its value. As a means of information acquisition, the time required for the planning process directly affects the value of the information. Especially for emergencies, if the satellite cannot acquire information and report it to the user in time, it will cause great losses. Meanwhile, the existence of many uncertainties in the planning process leads to error accumulation, which negatively affects the outcome or could even result in task failure.

(4) Requirements in terms of efficiency and reliability for satellite-borne processing algorithms have improved.

In the current satellite mission planning system, the speed at which hardware is upgraded does not correspond to the growth rate for constraints and demands; at the same time, the wide range of uses of satellites in human life means that the satellite mission observation density also continues to increase. The problem associated with agile satellite mission planning has already been proven to be an NP-hard problem. In view of this, a more effective solution is required for the satellite-borne processing algorithm, with a more reliable outcome.

DETAILED DESIGN

FUNCTIONAL MODULES OF AUTO MISSION PLANNING SYSTEM

The satellite auto mission planning system can receive the status and resource information from other subsystems, and integrate these data to arrange the imaging task demands. Based on the analysis of the working process of the satellite, the function of the mission planning system is divided into seven modules. Table 1 presents a comparison of the functions of each module in traditional and autonomous satellites.

Tab. 1. Comparison of features of modules in mission planning system

Modules	Autonomous satellite	Traditional satellite
User requirements integration	Diverse tasks	Single source
Environmental information analysis	On-board	On ground station
Imaging task planning	Flexible process	Fixed routine
Action control and prediction	Online formation	Off-line operation
Load data processing	Big-Capacity Data Disposal	Without it
Data transmission and signal communication	Real-time upload and return	Batch transmission
Structure and parameter adaptation	Automatic adjustment	Manual adjustment

The following schematic diagram incorporates the characteristics proposed above for an on-board mission planning system for future imaging satellites.

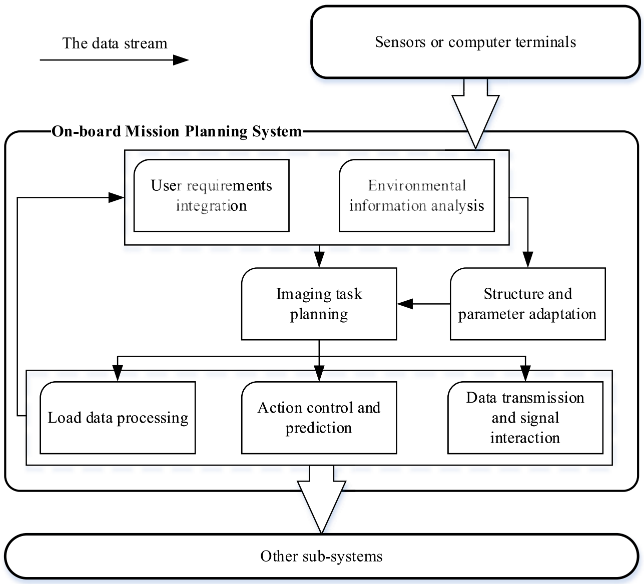


Fig. 2. Structure of proposed on-board mission planning system

Next, the function of each module and the mutual relations between modules are described in detail.

User requirements integration: with the deepening of research on collaborative multi-satellite operations and the developments in hardware and software design of imaging satellites, the reception of multi-source task information is an increasing trend in the future application of imaging satellites. Multi-source task information refers to information from many different devices, such as ground stations, mobile terminals, other satellites, and other loads. As user demands are becoming increasingly complex with increasing uncertainties, the process of requirement integration has to be completed on-board. It includes requirement generation, requirement decomposition, strip division, and other tasks, with all of the requirements ultimately included in a unified standard satellite mission planning system.

Environmental information analysis: Environmental information refers to the attributes that influence the completion of a satellite-imaging mission, including the external and internal environments. Weather conditions, light conditions, and the distribution of facilities (such as ground stations and the positions of other satellites) constitute the external environment of the satellite, which is usually determined through a communication link on the exterior of the satellite or calculated and analyzed based on known information internal to the satellite. The internal environment refers to storage space, the use of electricity, the health state of the satellite, etc., and can be read directly from the other modules of the satellite. It can realize two functions based on the provided information: One is to determine whether the system needs to adjust the task planning scheme by checking the environmental information according to the set rules, the second is to reduce the size of the solution domain occupied by mission planning for the satellite to improve the operational efficiency and to ensure that the mission planning scheme can be executed for final profit.

Imaging task planning: The purpose of this module is to generate a feasible plan for guiding satellite movement by analyzing all valuable information. Mission planning usually needs a relatively optimal solution considering all feasible solutions to strengthen the reliability and shorten the planning time and heighten the benefit. This is a multiple objective planning process; however, there are many practical constraints when the planning module is working on-board, in which case it is impossible to optimally reach all objects. The computation efficiency and optimization results of the different algorithms is also different under different kinds of constraints; thus, mission planning algorithms should be self-determined according to the requirements of different environments, in order to improve the overall optimization effect.

Action control and prediction: The action sequence of a satellite can be generated based on the constraints imposed by satellite actions and environmental information. Implementation of satellite action involves monitoring and control by other sub-systems of the implementation of the directive, and monitoring the feedback of information to this module. There are a wide variety of satellite actions, and there are some specific relationships between actions, which requires the appropriate action sequence to be determined based on these relationships. In addition, the module also scientifically predicts the actions of resource consumption, including feedback to the task planning system to assist decision-making. The resource consumption of each action is also an important factor in affecting the task-planning scheme and is difficult to predict; therefore, determination of the parameter in the predictive function has to correspond to the implementation of the actual action at each time, to finally improve the prediction accuracy.

Load data processing: Through the analysis and processing of the information obtained from different loads, some useful knowledge can be extracted from the image, which can lead to new task requirements. For example, by processing the signals received by the satellite, such as electronic loads and infrared loads, the satellite can determine whether the target is a current suspicious target or not, and generates the observation mission to the suspicious object. The satellite can also be used in the planning process of the potential demand generated by processing the load data. For example, the use of an optical or multi-spectral imaging load can be used to quickly sense imaging regional meteorological conditions, and determine whether it will affect the imaging planning task scheme and need corresponding adjustment.

Data transmission and signal communication: Due to the limited data link facilities, the present satellite communication system is composed of an oriented high-speed network and an un-oriented low-speed network. If the satellite transmits data by the high-speed network, advance request for transmission to the relevant object is essential; in contrast, a low-speed network can transfer instructions at any time, because the orientation of the antenna attitude is unlimited, but the transmission rate is slower. The satellite can communicate or transmit data and information to the ground unit or other satellite data and information through both methods. This module design can reasonably use limited transmission data resources to realize effective communication between the satellite and ground station. It enables the satellite to transmit data while relative positions are changing dynamically, as well as while all kinds of required information is obtained from other facilities.

Structure and parameter adaptation: The complexity and variety of the environment on the satellite means that there are many parameters and models that need to be adjusted according to the actual situation. However, resources and constraints cannot be accurately predicted, so the system needs to be able to select the appropriate structure and system parameters flexibility and automatically. In the face of complex task demands, especially under conditions of multi-source information, the system processing flow is not exactly the same for different task demands. This requires the algorithm structure and parameters to be selected according to the actual situation.

FUNCTIONAL STRUCTURAL DESIGN OF SATELLITE OPERATION

Based on the idea of the integration of satellite and ground operations, this paper proposes the framework for the Earth observation system of a new imaging satellite shown in Fig. 3.

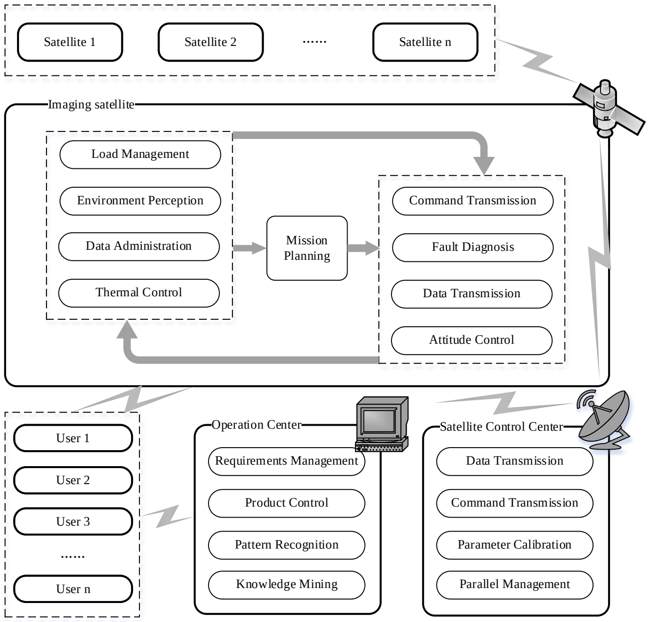


Fig. 3 Framework of the proposed Earth observation system

As shown in Fig. 2, the role of the satellite has been converted from that of a simple instruction executor into an agent with decision-making ability. The satellite can adapt to changes in the environment and resources and realize operations such as task processing, mission planning, and real-time adjustment on board, before deciding whether to carry out the task of planning according to the observation results and the environment. This is a so-called event-oriented program structure: different events can trigger the operation of different modules in the program. Meanwhile, addressing the diversity of the environment and demands requires the satellite to have the ability to base its calculations on a variety of structures and a variety of algorithms. Although computational resources are precious on the satellite, the task planning system cannot cover all operational processes, and it still needs many functions in other sub-systems as support. (e.g., the status information for other subsystems and the part function needs to be supplemented by the ground system). The ground station can establish and maintain some knowledge base (planning algorithms library, general function library, system structure pattern database, etc.) in order to reduce the cost of learning on board and achieving flexible task planning as well. In this system framework, demands upload by means of the "mission-type" instead of the "instruction-type," avoids a considerable amount of unnecessary processing by the ground station, thereby greatly reducing the fractional pressure, and taking advantage of the realization of the features in the auto mission planning system.

KEY TECHNIQUE

EXPENDABLE DYNAMIC DATA DESCRIPTION FRAMEWORK

Next generation agile EOSs face a more complex and uncertain mission environment, which is quite different from those faced by current EOSs. Thus, considering the strict environment, like the concept of "JIT", next generation EOSs should have the ability rapidly respond to the dynamic environment by using dynamic mission information collected from different data sources.

This aim can be achieved by implementing a unique expandable data description framework to transfer mission data (i.e., in text, image, and video format) from different data sources, including analyzing these data to generate information and ensuring an efficient mission execution plan. This framework can offer any data source (e.g., an environment detection satellite) in the EOS control system the ability to exchange data with other data source and process mission data under a unique data framework. In addition, this framework ensures that systems using the framework have the ability to process data described under this framework irrespective of the data source and to ensure a similar result when the same data is processed by different process units. Finally, this framework should be expendable to reduce costs once external detectors are included in this system.

FLEXIBLE EARTH OBSERVATION MISSION PREPROCESS TECHNOLOGY

According to our research, the time cost of earth observation mission preprocesses can significantly affect the efficiency of mission planning and scheduling software. Moreover, the process precision can also affect the final observation profit. Thus, the preprocessing technology is also very important. Current mission preprocess technology divides all of the earth observation demands into n different meta-tasks, which are studying volcanoes). It should be noted that because data mining is computationally intensive in terms of resources, most of these processes will be operated off-board. Plugins will be constructed to enable the final output of the data mining process to be uploaded to the EOS onboard operation system.

APPLICATION EXAMPLE

TEST SCENE DESIGN

Some imaging satellites carry two loads: the main load is the imaging camera, which acquires the image information and the secondary load is a cloud detector, which can detect real-time weather conditions 10 minutes ahead of the flight of the satellite. The satellite parameters for the simulation test are provided in Table 2, whereas its load parameters are listed in Table 3.

Tab. 2. Satellite parameters

Parameter	Value
Semi-major axis /(km)	6928.14
Height/(km)	550
Eccentricity	0
Inclination /(°)	97.5976
Perigee /(°)	0
Lon. Acsn. Node/(°)	135
Storage/(GB)	100

Tab. 3. Sensor parameters

Type	Parameter		
	Shape	Vertical half-angle	Horizontal half-angle
Cloud detector	Rectangle	45	75
Imaging lens	Rectangle	45	45

Table 4 lists a batch of required properties for satellite mission planning in a period of time, including task types of identifying, searching and tracking. The task id was uniformly numbered by the transport control center; image time is determined by objective conditions such as user demand and environmental information; the image time window (imaging starting and ending time) is calculated by using the orbit parameter of this satellite and each of the task coordinates; cloud level means the cloud thickness detected by the probe during an imaging task (usually the more cloud the worse the image quality.

Traditional satellite mission planning systems cannot acquire cloud cover information; hence, it requires integration of demand with resources on the ground to generate a feasible plan, which would then have to be uploaded to satellite via a high-speed network. A high-speed data transmission network has directionality and is related to the distribution of ground stations. In these experiments, we assume two time windows for data transmission as below:

Tab. 4. Task attributes received by imaging satellite

Task id	Imaging time /(s)	Starting Time	End Time	Task Arrival Time	Cloud Level
1	10	02:14:30	02:17:58	00:00:00	2
2	16	02:17:50	02:21:15	00:00:00	3
3	15	02:27:50	02:31:10	00:00:00	4
4	14	02:35:39	02:39:02	00:00:00	5
5	08	02:21:41	02:25:12	00:00:00	1
6	06	04:11:28	04:14:50	00:00:00	2
7	12	03:51:56	03:55:21	00:00:00	4
8	14	03:52:47	03:56:11	02:12:00	8
9	06	03:51:52	03:55:15	02:12:00	2
10	10	03:50:46	03:54:10	02:12:00	2
11	14	04:08:33	04:11:58	02:12:00	9
12	12	04:09:46	04:13:10	02:45:30	3
13	09	05:32:30	05:35:56	02:46:12	7
14	06	05:32:33	05:35:55	02:46:12	2
15	08	05:53:26	05:56:51	02:59:28	8
16	10	05:52:58	05:56:22	02:59:45	2
17	06	05:53:57	05:57:21	03:00:07	1
18	06	05:40:47	05:44:07	03:00:22	3
19	08	05:39:18	05:42:40	03:00:24	5
20	10	05:39:17	05:42:39	03:00:24	6

Tab. 5. Ground station information

g	orb	FST	FET
1	1	01:37:23	01:43:47
2	1	01:40:20	01:46:39

An autonomous satellite mission planning system would have no need for information processing throughout such as upload orders or codes, because each task carries a small data volume. This would enable us to use a low-speed monitoring network, or to repeat satellite communication, to use a short message, and other forms of upload instructions to realize satellite autonomous planning and management.

Because of the limited range of the cloud probe, the mission planning system will be event-driven in autonomous mode, thereby ensuring that planning occurs within the range of the cloud probe. We compared the test results of different algorithms in a framework based on two systems by applying an improved dynamic programming (IDP) algorithm and depth-first search (DFS) algorithm in the two frames. This enabled us to obtain the results in a different frame with a different algorithm.

ANALYSIS FOR TEST AND RESULTS

We combined the processes in Sec. 5.1 by using C++ language in Visual Studio 2010 to build the testing platform and installed this system in a computer with the following configuration: processor model core i5 (2.6 GHz), memory 8 GB, 64-bit Windows 7 operating system. Next, we input the original data for testing, after which we obtained the final mission plan and simulation result for the completion of each task. This allowed us to generate an index for the direct evaluation of system planning. The utilization rate for return resources, dynamic task response rate, environmental change response rate, and program running time are as follows:

Utilization rate for return resources: In all returned data, the proportion for valuable data. In reality, the value of data is related with many factors. In this test, if the cloud level is over 5, then we consider the image to be worthless.

further divided into different observation windows based on the cost of resources. This method ignores the differences between different earth observation demands, and may not be able to support complex earth observation missions in the future.

Addressing this problem requires the use of flexible earth observation mission preprocess technology. This technology is intended to support different demand types (pre-ordered mission, dynamic arrived mission, and rapid response mission) with different types of preprocessing methods considering the responsiveness requirement (i.e., in the case of rapid response missions, some of the highly time-consuming processes, e.g., the mission merging process, can be eliminated). Furthermore, flexible preprocessing technology has the ability to forecast the strict mission constrains in the next planning horizon, based on current onboard resource conditions, when new mission requirements are uploaded. This facilitates efficient planning by the mission planning software. Finally, this technology should have the ability to eliminate redundancy requirements to ensure the efficient division of limited onboard computational resources.

CONFIGURABLE MISSION PLANNING AND SCHEDULING ALGORITHM

The importance of the mission planning and scheduling algorithm to increase the effectiveness of earth observation missions is undeniable. Currently, satisfying the increasing demand for earth observation with limited earth observation resources is problematic. Thus, a flexible and configurable (i.e., capable of supporting different types of earth observation missions under fluctuating environmental conditions) mission planning and scheduling algorithm to solve this problem is obviously important.

The method could use machine-learning methods to extract information from past mission sets to forecast the conditions of future mission areas. Then, it could dynamically configure its mission planning and scheduling operators to fit the future mission environment. This method focuses on the dynamic factors of an earth observation mission and thus can be expected to achieve an increase in mission planning efficiency. Note that because the adjustments made to this method are intended to enable it to fit a dynamic mission set, the machine-learning process can be accomplished off-board. However, this method also needs past mission information to extract mission area characteristics of different situations.

EOS OPERATION SYSTEM ONBOARD RECONFIGURATION TECHNOLOGY

Next generation EOSs face the requirement of cooperation with other EOSs in an EOS network to complete complex earth observation missions. In special situations, an EOS may communicate and cooperate with other EOSs in different EOS networks. Thus, next generation EOSs should have the ability to perform a partial onboard reconfiguration (especially the communication and mission planning mechanism) to fit the requirements of different EOS networks. On the other hand, onboard system reconfiguration would also be able to solve some onboard hardware errors owing to the wide application of FPGA and onboard EOS hardware health monitoring technologies. When an onboard hardware error occurs, the FPGA will be activated and the onboard system will be reconfigured in real time to ensure uninterrupted operation of the other parts. This technology would reduce the maintenance costs and increase the error tolerance ability of next generation EOSs.

"PLATFORM PLUS PLUGINS" SYSTEM FRAMEWORK

Current EOS operation systems are mostly unchangeable once they are built. However, next generation earth observation missions require the EOS operation system to change the functions of its subsystems to meet special observation requirements. Moreover, it is noticeable that in most of the life cycle of an EOS, the onboard computational resources are not completed used. In addition, the function of a computational resource may not remain unchanged during the life cycle of the EOS (e.g., the function of EO-1 has been changed from a high-resolution EOS to an EOS network pathfinder). As a result, a "platform plus plugin" system framework is needed. When the EOS mission environment is changed, this framework would make it possible to upload some new plugins to the onboard operation system to help it accommodate the new environment. This technology is expected to reduce the development and maintenance costs of the EOS.

4.6 USER DEMAND AUTONOMOUS MINING TECHNOLOGY

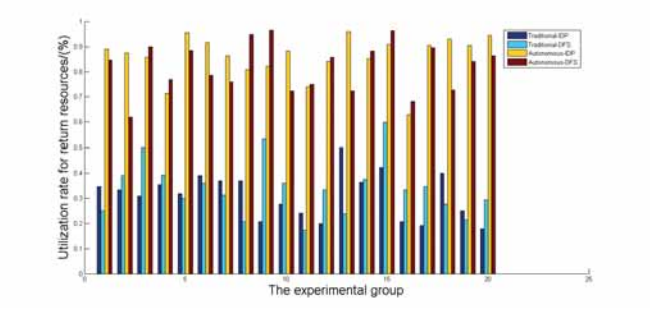
Current earth observation missions are mostly offered by professional EOS users, who are familiar with the constraints and abilities of the EOSs they want to use. However, this situation is expected to change in next generation earth observation activates. The users of next generation EOSs will mostly be nonprofessional users, and most of them would have little knowledge as to how an EOS functions. Thus, they would not have the ability to offer a standard earth observation mission. This problem would have to be addressed by equipping the EOS mission control system as well as the EOS onboard operation system with the ability to perform autonomous user demand mining. Some of these demands (but not limited to) could be: help users to divide their requirement into standard earth observation missions; help users to find the specific high-value information in which they are interested (e.g., users who are concerned about wildfires would obviously find the infrared information valuable); to help important users build their own knowledge database based on the missions they offer; decision making technology based on key mission information, which means that the EOS operation system could autonomously produce earth observation missions based on a user's knowledge database (i.e., when EOS receives an alert that a volcano may erupt, a new observation mission will be produce autonomously to offer rapid response information to institutional users

Dynamic task response rate: Generally, task processing and planning are considered to occur in real time shortly after task arrival.

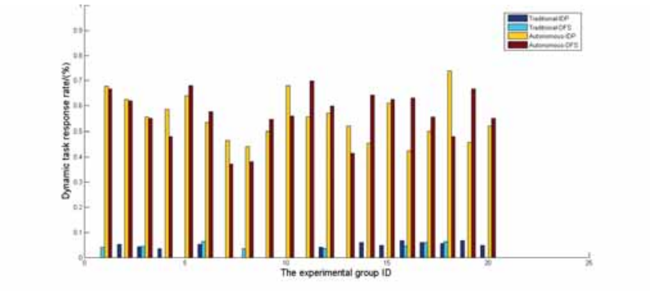
Environmental change response rate: it is the ratio between the task of automatically adjusting the imaging strategy when detecting the related environmental information and total task quantity.

Program running time: it is the total time required for a full simulation when program initiation to all tasks is included.

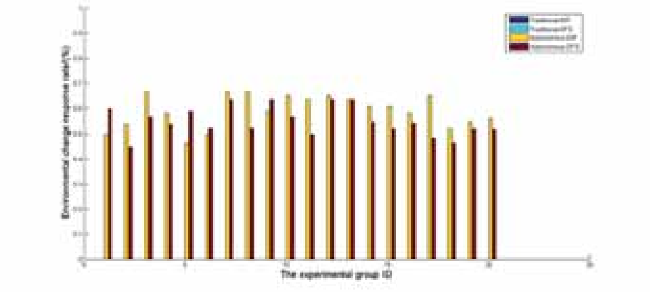
Parameter input was accomplished by using a pseudo-random function, as a result of which we designed 20 sets of input data with different quantities and characteristics. The results in Fig. 4 were generated by performing a simulation and analysis on these datasets.



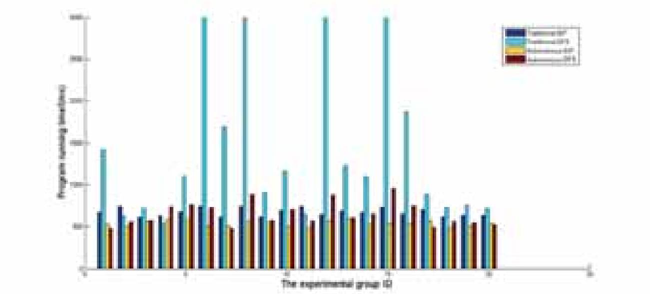
(a) Utilization rate for return resources



(b) Dynamic task response rate



(c) Environmental change response rate



(d)Program running time

Fig. 4. Comparison of the results obtained for the traditional system and simulation systems.

Figure 4(a) indicates that the data transmission utilization rate has greatly improved in the case of the auto mission planning system. This is attributed to the ability of the auto mission planning system to actively avoid clouds in the process of observation arrangement, during which it will choose low cloud level as the priority task. In fact, tasks conducted in the presence of high cloud level might not be useless; thus, if the satellite is equipped with a mature model recognition algorithm, it can arrange imaging and returning for all resources and time window conditions allowed to avoid neglecting to acquire some useful information. It can autonomously decide which information is useful and needs to be returned to the ground station after imaging.

In Fig. 4(b), it can be seen that the autonomous mission-planning model can effectively and timely process tasks dynamically upon arrival. In contrast, traditional satellite mission planning systems are only capable of conducting real-time planning in the data transmission time window; hence, their dynamic task response rate is 0. When we require imaging in the event of an emergency, a traditional satellite mission planning system would not necessarily be able to respond.

Figure 4(c) shows that a traditional satellite cannot respond to dynamic environmental change because it cannot detect and analyze the influence of weather conditions on mission planning. Even if the ground station succeeds in re-planning after receiving the real-time satellite running environment information it would be unable to upload the orders or instructions to the satellite in time. An autonomous satellite mission planning system is equipped with an additional module to detect and process environmental information. This capability enables it to proactively avoid the impact of poor environmental conditions and to improve the overall planning.

In Fig. 4(d), it can be seen that the auto mission planning system generally requires less time to run than the non-autonomous system, but this conclusion would have to be confirmed by investigating the influence of the different structures of the two planning systems on the program running time by performing additional testing. Because of the complexity of the problem, we decided to set the maximum elapsed time as 3000 ms to prevent a situation of plunging into a local optimum. Traditional planning systems using a DFS algorithm to artificially set a desired target value will stop running when the desired target is achieved; otherwise they continue searching the solution space. In the autonomous system, the problem is decomposed into several sub-problems according to the time, thereby greatly reducing the solution space and simultaneously reducing the running time of the program to within a controllable range. The use of different algorithms in the system has an impact on the time efficiency and the optimization effects, which differ accordingly. Establishing the relationship between the algorithm and the input parameters is a problem that needs to be solved in the next step of system design.

CONCLUSION

This thesis elaborates a design frame for an auto mission planning system for imaging satellites. The new application environment and new task requirements divide the satellite mission planning system into two subsystems: the satellite and ground station systems. The imaging satellite needs to realize four main functional requirements and the system was applied to three typical scenarios to solve problems encountered in the practical applications of satellites to constantly improve its system design in different scenarios. In the future, we plan to mainly focus on enabling the six key technologies to improve the effectiveness of the imaging satellite as a tool to obtain information on a variety of human activities.

In reality, China's satellite network is becoming increasingly complex. Thus, once users have proposed an imaging task, they do not necessarily understand the characteristics and constraints of each satellite; neither do they care about how the system allocates resources for the operation. Under the proposed system framework, users only need to put forward their desired results, whereupon the system would determine how to arrange the resources to achieve these results. Finally, the simulation test conducted with both the traditional and new autonomous satellite mission planning systems, indicated that the new satellite mission planning system can optimize the satellite mission planning time complexity and resource utilization efficiency with higher stability and faster convergence speed.

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest gratitude to my school, the National University of Defense Technology, who provided me with a perfect intellectual atmosphere, such that I could write this article successfully. This research is supported by the National Natural Science Foundation of China (Grant Nos. 71331008 and 71101150). Finally, I want to thank all my schoolmates, especially each person working in my lab, for their encouragement and support.

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