Summary of Research on Satellite Mission Planning Based on Multi-Agent-System

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Abstract. With the continuous development of space science, the number and types of space missions are increasing day by day. Reasonable mission planning plays an important role in fulfilling space missions to the maximum extent with limited satellite resources. Satellite mission planning modelling based on multi-agent system (MAS) is a bottom-up method. This article introduces three specific solution methods and compares and analyses them. Finally, the future development direction of the MAS mission planning problem is analysed.

Keywords: Multi-agent system, Satellite mission planning, Contract net protocol, Auction algorithm, Swarm Intelligence.

1. Introduction
In 1957, the Soviet Union successfully launched the first artificial earth satellite, opening a new era of human exploration of space. For decades, the mysterious space environment and abundant space resources have deeply attracted various countries. The pursuit and exploration of space by various countries has never stopped, and space technology has also been greatly developed. Since entering the 21st century, the rapid development of artificial intelligence interdisciplinary has also brought a new round of opportunities and challenges to the aerospace field.

A series of satellite traditional tasks such as satellite launch, imaging reconnaissance, and inter-satellite communication are all controlled and managed by ground systems. On the one hand, ground control management has disadvantages such as communication delay, and it is difficult to adjust tasks in real time in emergencies; on the other hand, the increase in the number of satellites requires a lot of manpower and material resources to adopt traditional ground control methods, and the burden of communication and commands increases. It comes with high operating costs [1]. Therefore, satellite autonomous mission planning is particularly important.

2. Background introduction

2.1. Satellite mission planning
Taking imaging reconnaissance satellites as an example, satellite mission planning is a complex problem with multiple resources, multiple tasks, multiple constraints, and multiple optimization goals. Its basic
elements generally include satellite resources, observation tasks, ground station resources, constraints and optimization goals, etc. The description of satellite resources includes satellite orbit, type and resolution of on-board sensors, attitude maneuver angle and speed, on-board energy and storage capacity, etc. Constraints generally include satellite usage constraints and mission demand constraints. Satellite usage constraints include time window constraints, maximum roll angle limitations, maximum maneuver speed limitations, on-board energy and storage capacity limitations, etc. Task requirement constraints include the time limit to complete the task, the geographic location of the target, the timeliness of observation requirements, the image type and resolution requirements, the priority requirements of each task, etc. Optimization goals include mission completion, target coverage, minimizing the workload of a single satellite, and energy consumption [2].

In summary of the above elements and constraints, satellite mission planning allocates limited satellite resources to multiple observation missions based on user mission requirements and satellite attributes, combined with ground station attributes, and determines mission execution time and action sequences to maximize user needs. The research on satellite mission planning mainly focuses on two aspects. One is the establishment of mission planning models. Most of the models can be divided into integer planning models, constraint satisfaction models and multi-agent-based models. The second is the algorithm solving of the model. The algorithm can be roughly divided into deterministic algorithm, intelligent optimization algorithm and heuristic algorithm.

2.2. Multi-agent system
Agent is an effective method for modeling complex systems in a distributed computing environment. Modeling and simulation based on multi-agent system (MAS) realizes the overall modeling of the system by modeling the interaction between entities, and obtains the overall "emerging" behavior of the system.

It is a bottom-up modeling method, by abstracting the entities in the system and the environment into reactive and proactive Agents, and then using the appropriate MAS architecture to assemble them, thereby establishing a simulation model of the entire system. Realize the simulation of the overall behavior of the system. At present, MAS-based modeling and simulation technology has become one of the more effective methods for studying complex system problems. The hot and difficult point in the research of multi-agent systems is to use Agent technology to decompose a large system or a more complex system into small subsystems. Agents have communication capabilities with each other and can negotiate and collaborate with each other. In this way, an intelligent, autonomous and collaborative system is constructed.

3. MAS-based mission planning method

3.1. Contract net protocol
In the 1980s, Davis and Smith first proposed the concept of contract net protocol (CNP) [3]. In the contract net protocol, Agent is only divided into two roles, manager and worker. However, the roles of managers and workers are not set in advance. If any agent in the agent cluster undertakes tasks such as establishing task notifications, accepting bids, evaluating bids and selecting the best, and supervising the completion of tasks, then it is a manager Agent. And if it undertakes tasks such as accepting task notifications, issuing task bids, and performing tasks in accordance with the contract, then it is a work agent. This is a task planning mechanism that imitates negotiation, which dynamically allocates tasks through a series of behaviors such as calling for bid, bidding, evaluation, bid winning, signing, and execution.

When the traditional contract network agreement is applied to multi-satellite collaborative mission planning, there are the following shortcomings:

(1) The task bidding object is not targeted, and the management agent needs to broadcast the bidding information to all the working agents in the aerospace system, resulting in frequent system
communication, and the management agent must evaluate a large number of bid applications, resulting in excessive load;

(2) The confirmation of the contract requires multiple rounds of repetition between the management agent and the work agent, which is time-consuming;

(3) It is difficult to update the knowledge of bidders;

(4) Difficulties in subsequent learning.

In response to these problems, scholars have optimized the traditional contract network agreement to varying degrees. Yang Weiyi [4] designed a contract network agreement task collaborative assignment mechanism based on a dynamic centralized-distributed architecture, and based on this, proposed a multi-attribute bid evaluation strategy. Samir [5] expanded the negotiation process of the contract network agreement and added four preparatory stages to try to avoid the situation that the Agent breached the contract due to environmental changes after bidding and signing the contract. Sandholm [6] expands the basic contract types and proposes the concepts of exchange contract, cluster contract and multi-agent contract to avoid the generation of local optimal solutions.

3.2. Auction algorithm
Auction is an economic concept. It refers to a business activity that determines the ownership of commodities based on the bidding of participants based on a series of clear rules. Dimitri in the United States proposed an auction algorithm based on the idea of auction to solve the problem of resource allocation. Professor Jin Xing of Tsinghua University once proposed that auction algorithms can be introduced into multi-intelligence systems [7]. Auction is a fast and effective negotiation method, with strong operability, which can make the participating auction parties and bidders obtain ideal benefits. If it is used in the task planning of a multi-agent system, an efficient mapping can be established between tasks and agents. Therefore, the auction algorithm is a method to solve the task planning of the multi-agent system.

The types of auctions include British auctions, Dutch auctions, sealed first-price auctions, sealed second-price auctions, and so on [8]. Vickrey constructed a symmetrical independent private value model, solved the equilibrium bidding strategy of the English auction and the Dutch auction, and showed that these two auctions can achieve Pareto efficiency allocation. In response to the problem that the centralized command and control method is susceptible to interference in a highly dynamic air combat environment, and the timeliness of redistribution is not high in emergencies, Gu Jiao Jiao [9] proposes a fully distributed cooperative air combat attack decision model based on an improved combined auction algorithm. In order to reduce the amount of communication and calculations, Palmer [10] proposed a distributed collaborative auction algorithm. The basic idea is that each agent can independently calculate the consumption of each task, and can sort according to the consumption of tasks. After randomly generating the bidding order, each Agent will bid for the tasks it wants to perform in turn according to the bidding order, combined with its own task sequence. Ran Huaming [10] proposed a multi-machine cooperative task allocation algorithm based on two-step distributed cooperative auction. Through the distributed collaborative auction bidding for task targets and the two-step auction of distributed collaborative auction bidding for the base, the optimization of the multi-machine collaborative task allocation problem is realized.

3.3. Swarm-based intelligence
Swarm Intelligence (SI), also known as Bio-inspired networking (BIN). It is a self-organizing characteristic of collective intelligent behavior that emerges from a group of free individuals (Agent) following simple behavior rules, through local communication between individuals and the interaction between individuals and the environment. It is an abstraction of the orderly group behavior exhibited by social organisms or artificial groups in the real world [11].

Swarming behaviors are common in natural biological systems, such as ants seeking paths, bird flocks foraging, and geese migration. Swarm-based models include Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), Artificial Immune System (AIS), Intelligent Water Drop Algorithm
(IWD), Group Search Optimizer (GSO), Fish Schooling Algorithm (FSA), Bacterial Chemotaxis Algorithm (BCA), Firefly Algorithm (FA), Honeybee Mating Optimization (HBMO), Shuffled frog Leaping Algorithm (SFLA), Invasive Weed Optimization (IWO), Bat Algorithm (BAT) [12-17]. At present, the most widely used swarm intelligence method in task planning is the optimized ant colony algorithm. Ant colony algorithm is a population-based bionic evolutionary algorithm proposed by Dorigo by simulating the collective path-finding behavior of ants in nature. By modeling and simulating the foraging behavior of ants, Dorigo proposed ACO and successfully tested the well-known benchmark TSP traveling salesman problem, allocation problem, scheduling problem, search and combinatorial optimization problems, etc. [18].

4. Conclusion

With the increasing difficulty of space missions and the gradual deterioration of the space environment, multi-satellite systems have gradually replaced single-satellites and have become a current research hotspot. Multi-satellite collaborative mission planning has complex constraints and difficult solution. The common model is too ideal and has a certain gap between reality. In view of this, the method based on multi-Agent modeling is widely used in multi-satellite mission planning modeling. This paper combs the method based on multi-agent modeling, discusses the principle and research progress of the method, and has a certain guiding role for the follow-up task planning research.

At present, the problem of multi-agent-based satellite mission planning has become a key concern of researchers, and it is an urgent problem that satellites need to solve in engineering applications, although certain results have been achieved on some issues, there are still problems such as relatively single mission planning model, relatively simple research on dynamic mission planning, and insufficient research on multi-type satellite cooperative mission planning.

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