Multi-level Optimization Mission Planning and Control Methods for Unmanned Aerial Vehicle

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Abstract—Autonomous mission planning system for unmanned aerial vehicle (UAV) has the ability to perform complex tasks, during the process of task execution. Due to their own and external conditions may change, Effective self-re-planning aircraft can adapt to these changing conditions in the uninterrupted implementation of the mission objectives. Mission planning is a complex problem. By gradual decomposition of a large target for a number of multi-level independent sub-goals, it can reduce the overall complexity, without losing the characteristics of the whole system. At the same time, the next-generation human-machine interface can increase the ability of UAV operator's assistant decision and control accuracy.

***Keywords—mission planning*, t*he next-generation human-machine interfa*cet, unmanned aerial vehicle, augmented reality**

I. Introduction

Mission planning and control methods for UAV have been developed mainly in the military field, with the consolidation of technologies, the usage of unmanned aerial vehicle (UAV) is now extending to civil market. Currently, operating UAV uses rudimentary planning technologies, such as following pre-planned or manually provided waypoints. Such operation modalities only allow limited operational flexibility and restrict applications to ones such as high-altitude reconnaissance, exploration, and target assignment. UAV mission planning and control is an important part to determine their ability, the system is composed of the ground component and the air component [1]. With the development of the software, hardware and the intelligent control technology, the real-time task re-planning on board will play a more important role, while ground controlling will mainly act as a supervisor. On the basis of mission demand, a mission planning system gathers information from multi-channels, analyzes the environment, provides the policy-making basis for the mission plan method, schedules resources, defines goals, and realizes the optimal task execution [2].

For UAV systems, the purpose of mission planning is to identify a best flight route and a valid control strategy on the route. In terms of timing, mission plan can be divided into pre-plan and real-time plan. Pre-plan is enacted before a UAV taking off, mainly integrates mission requirements, environmental and meteorological factors such as existing information to develop programs. Real-time plan, also known as online re-plan, is made in flight for UAV to take emergency plans according to the actual situation and environment. From the view of the level of functionality, a mission plan is a complex process, which includes path plans, payload plans, data chain plans and emergency recovery plans. Using hierarchical optimization method, we can develop effective mission planning method [3].

II. Hierarchical Optimization of Mission Planning

For the UAVs with specific mission objectives and constraints, tasks and trajectory planning problem is concluded to the following three points:

1) Choice and classify goal subset so as to maximize the mission effectiveness and meet the constraints;

2) Evaluate the target trajectory so that the aircrafts achieve goals safely and timely;

3) Match the mission control and the trajectory.

As the runtime environment, its flight performance, mission objectives, constraints are all changing while a UAV performing tasks, mission planning problem is very complex. In-flight re-planning of tasks is required to adapt to sudden changes.

UAV mission and trajectory planning problems can be attributed to the constrained statistical optimization problems. The physical characteristics of the aircraft itself (fuel load, flight envelope and subsystem capabilities) are inherent constraints, while the specific task constraints (survivability, mission objectives, etc.) are external constraints. We should count on the current and future uncertainties of states of both the aircraft itself and the operating environment, and take them into account while making and assessing task plans. Finally, the mission planning system is an optimization problem to identify the flight plan of almost maximum mission effectiveness so as to meet the specific constraints [4].

Mission planning can be achieved on board or on the ground, as shown in Figure 1(a) and (b) :

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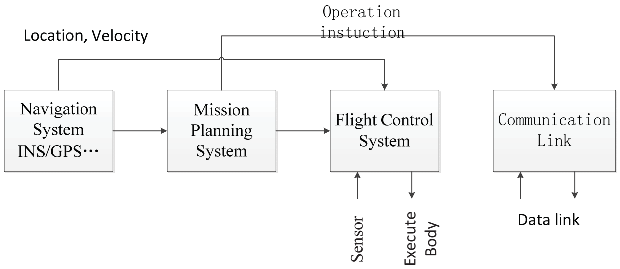
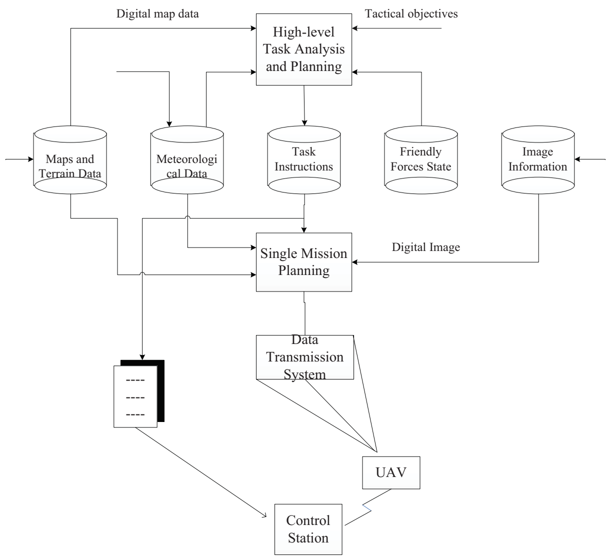


(a) on-board part



(b) Ground part

Figure 1. Structures of a mission planning system

With the improvements of the capabilities of airborne equipments and control systems, more functions of the mission planning system will be realized on board, and the ground parts will act as supervisors.

A. Decomposing of mission planning

Since the complexity of the mission planning problem, we stepwise decompose it into separated sub problem, and then optimize it.

Complex problems need layer decomposing and multi-level optimizing. The key is to coordinate the sub-problems, which ensures that the whole system is of constrained optimization. The multi-level optimization means to decompose a complex optimization problem into several simple step by step problems, respectively optimize them, and then coordinate the results of the upper and the lower layer [5].

Consider the following description of a typical problem

$$\min_{\overline{x},\overline{y}} f(\overline{x},\overline{y}). \tag{1}$$

Constraint conditions : $\overline{g}(\overline{x},\overline{y}) \le \overline{0}$;

Vector : $\overline{x} = \left[x_1 x_2 \cdots x_N\right]^T$;

Vector $\overline{x_i}$ corresponds to the lower N sub-problems. When we use Laplace operator and the Kuhn-Tucker multiplier vector $\overline{\gamma}$, the above equation can be written as:

$$L(\overline{x},\overline{y}) = f(\overline{x},\overline{y}) + \gamma^T \overline{g}(\overline{x},\overline{y}). \tag{2}$$

If we set the values of the coupling vector $\overline{y}$ and the multiplier $\overline{\gamma}$, the optimization problem will break down. Assume that Laplace operator can be rewritten as the sum of decoupled Laplace operators while setting the value of the coupling vector.

$$L(\overline{x},\overline{y}) = \sum_{i=1}^{N}\left[\ f_i(\overline{x}_i,\overline{y}) + \gamma_i^T \overline{g}_i(\overline{x}_i,\overline{y})\ \right] \equiv \sum_{i=1}^{N} L_i(x_i, y). \tag{3}$$

At this point, when we give the value of $\overline{y}$, every question corresponds to a Li, which can be used to solve the optimization problem of decoupling.

$$\min_{\overline{x}i} f_i(\overline{x}_i,\overline{y}). \tag{4}$$

Constraint conditions : $\overline{g}_i(\overline{x_i},\overline{y}) \le \overline{0}$ 。

B. Hierarchizing of task planning

In fact, the planning and management functions, which manage planning process and the execution of the plans, can be the interface of mission planning algorithms and other onboard equipment, such as fault detection and isolation, redundancy management, sensors and images, navigation control systems. As shown in Figure 2, mission planning system can be divided into three layers: the highest level (task level), the middle layer (active path layer) and lowest (Safety Flight layer). Firstly, a framework is created at the top layer of the mission. Secondly, detailed plans of immediate activities and strategic plans are produced in the middle layer. And finally, the commands for sub-systems of the UAV to perform tasks are generated at the lowest level, and ensure the safety of the aircraft [6].

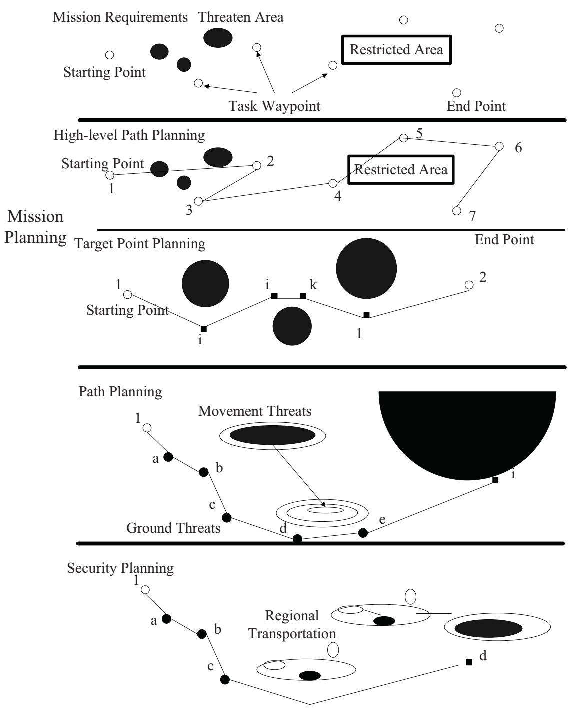


Figure 2. layered graph of Planning

C. *On board re-planning*

While UAVs performing tasks, as the runtime environment and the aircraft itself are both changing, mission on-line re-planning is required to achieve the best mission result. Artificial intelligence technology has been applied to more and more UAV mission planning systems, as a result of which a mission planning system based on artificial intelligence emerges. It takes effects in the problem as-a series of actions to minimize the cost goals [7].

Timely and correct situational perception is a prerequisite for the implementation of re-plans. Agent is an entity, which operates in a dynamic environment with highly self-control abilities. The fundamental purpose is to accept the commission of another entity and to provide help and services, driven by the target, Agent Initiative take all necessary actions Including social, learning and other means to sense and adapt to the environment and appropriate response dynamic environment changes.

The online mission re-planning process begins with real-time receiving awareness information from the UAV. And then it selects several track points according to the original task, inspects and adjusts them so as to meet the requirements of a variety of constraints, on basis of which, a valid path is generated by computer according to optimization criteria (such as the shortest path analysis). If all points on the route pass the test criteria, the route is available.

For those failed points, new points that meet the requirements can be inserted in the vicinity of the track. Repeat the test until an available route is found. Additionally, it also works to modify the existing track points. Finally, special regions are simulated.

In addition, emergency measures, such as identifying a safe return passage and emergency landing points and the routes transfer policy(from any point on the route to a safe return passage or from the safe return passage to emergency landing points or airports), should be considered so that the safe return of the aircraft could be ensured.

The process is as follows:

1) Input tasks: requirements of fight areas for each task;

2) Identify typical track points, and test them;

3) Manually or computer-aided generating of flight path;

4) Check all factors. If anyone is adopted, propose amendments and return to *2)*;

5) Check whether or not mission requirements are met. If they are not met, propose amendments and return to *2)*, or modify the task requirements;

6) Select the best control points on the flight path, Generating node control table and Enter the flight control data;

7) Determine the load control strategy, generating node control table and enter the flight control data;

A typical structure of UAV mission online re-planning system is shown in Figure 3. Environmental awareness, planning algorithm, assessment and recognition, which are key components of the system, directly determine the effects of the planning.

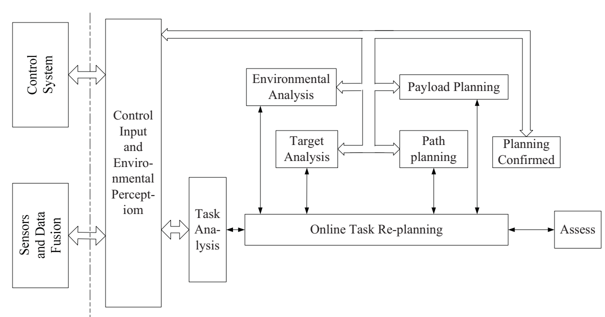


Figure 3. A typical structure of UAV mission online re-planning system

III. THE CONTROL INTERFACE IN FUTURE

As for UAV systems, the designers mainly concentrate on the aircraft itself, including the payload. However, statistics shows that the cost of ground system is between 0.5 to 4 times as high as that of a single UAV. Whether for a remote controlled UAV or for a highly autonomous UAV supervised by an operator, the good design of control interface facilitates operators. Thanks to the applications of the virtual reality and interactive voice recognition technology in the next generation of UAV ground control systems, user interface is friendlier so as to command UAV task accurately and effectively [8].

In addition, developed for different tasks, the current UAV systems, their ground control stations in particular, lack of general performance and interoperability. For example, the ground station of Predator can neither control the Global Hawk or the Pioneer, nor receive their images. Nowadays, the U.S. Navy and the Army have taken steps to solve interoperability issues between UAVs. A general ground control station with the ability to control various types of UAVs not only greatly reduces the cost of UAV system development and training, but also improves the flexibility to combat, thanks to which the interoperability between unmanned systems is achieved. Otherwise, it is the trend to integrate and miniaturize the ground control system.

UAV ground control system includes a large number of menu items and flight status display information. Most current systems are controlled by keyboard buttons and mouse, the inputs of which call menus with a variety of different options. The slow response and error- proneness of keyboard and mouse, along with a lot of manual and visual work will inevitably lead to low vigilance, inflexible operation, slow response and other issues. With the rapid development of computer technology and the increasing of applications, people need a more convenient and natural way to exchange information with computers.

A. Controlling based on speech recognition

Language is the most natural and effective way for human to exchange information. Introduced into UAV ground station control system, the speech recognition technology enables operators to manage information in the complex environment by using natural language. Meanwhile, resource utilization rate and workload are reduced. As commands and control applications are concerned, voice input improves system performance more than traditional mouse and keyboards in terms of the task completion time. By using voice input, operators can select the menu of system arbitrarily, they do not need to crouch to select the menu abundantly and do switch-operation with great care. Increased system feedback channel by using voice output, operators can receive real-time information of system getting through the man-machine dialogue. The UAV ground controller can reduce error operation caused by visual tiredness. The introduction of voice technology into UAV ground station control system makes the control system more intelligent and friendly.

The basic problem of statistical speech recognition can be interpreted as follows. If we give the input signal or characteristics sequence $O = \{O_1, O_2, \cdots, O_n\}$ and symbol set $W = \{W_1, W_2, \cdots, W_n\}$, the symbol string $W = W_1, W_2, \cdots, W_k$ can be solved by the constraints as follows,

$$W = \mathrm{argmax} P\left(W \mid O\right). \tag{5}$$

According to Bayesian formula, the above equation can be rewritten as,

$$W = \mathrm{argmax} \frac{P\left(W \mid O\right) P\left(W\right)}{P\left(O\right)} \tag{6}$$

As P (O) is determined by the input sequence, it does not affect the final outcome of the above equation to omit it. Therefore, speech recognition problem can be expressed as the following formula:

$$W = \mathrm{argmax} P\left(O \mid W\right) P\left(W\right) \tag{7}$$

From this perspective, the signal processing module pre-processes the input signal, and maps the collected voice signal set(S) to the characteristic sequence O. The voice recognition equipment of the human-computer interface of the future UAV ground control system establishes an audio command library, ensuring the recognition rate and speed, establishes the task instruction and intelligent processing algorithms for the UAV flight control characteristics. Ensure that the different operators of UAV can operate well and timely feedback the current key information of UAV to the operator. Process is shown in Figure 4:

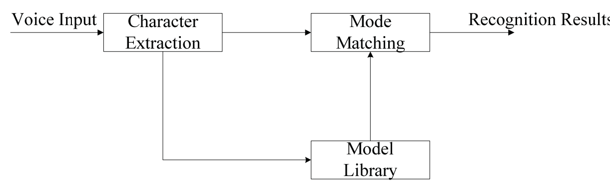


Figure 4. UAV controlling base on speech recognition

B. Mission controlling based on augmented reality

UAV with high autonomy has been a goal pursued by researchers. However, researches show that the applications of fully autonomous UAVs is difficult to realize in the expected future, because several supporting technologies, such as structure, control, sensing and artificial intelligence, cannot meet the development requirements of fully autonomous UAVs. Therefore, the remote UAV system, which has a presence in the interactive mode, is still an effective way to complete the tasks in the complex or uncertain environment [9].

Operator's capabilities to acquire information in training and actual combat can be improved by Augmented Reality-based UAV control method. Based on the UAV real-time video, using augmented reality display can get overlay key region feature extraction, target guidelines. Combined with the rapid and effective method of filtering and interpolation of telemetry data, it can establish good visibility and reliability UAV remote real-time display system, effectively improve the dynamic image of the flight status. The developing binocular vision system also improves the environmental perception of the operator so that we control UAVs more intuitively and accurately. Augmented Reality technology plays an important role in simulated training of UAV operators. Figure 5 shows Augmented Reality-based control of a UAV. Three-dimensional glasses and touch screen compose the configuration.

Figure 5. Augmented Reality-based control of a UAV

IV. CONCLUSION

Hardware, software and the development of intelligent control technology gradually improve the autonomy of UAVs. Moreover, the multi-level optimization method in UAV mission pre-planning and re-planning and the next generation human-machine interface enables UAVs respond effectively to the uncertainties in flight, so that the workload is reduced and the UAV operators perform tasks better.

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