Research on Automatic Decision Making of UAV Based on Plan Goal Graph

Dong Wang, Wei Zu, Hongxing Chang, Jie Zhang

Abstract—**Aiming at the problem of UAV automatic decision making in air combat, an algorithm based on Goal Graph Plan is proposed to solve the knowledge modeling in tactical decision making. The heuristic knowledge in the field of air combat rules was introduced to help UAV make the reasonable maneuvering decision. The structure of UAV autonomous decision making based on the plan goal graph is designed according to the manned aircraft control model. Simulation experiment of task planning of 2V1 air combat scenario is realized, the simulation results show that the algorithm is effective and real-time in solving the problem of autonomous decision making.**

I. Introduction

With the development of technology, UAV is becoming more and more important for air-combat, the grasp of UAV technology has a significant impact on a national air defense safety system. Air-combat is a multi-disciplinary intersect research, including a series of complex key issues, such as situation estimation, collaborative mission planning, tactical decision making and damage assessment. Multi UAV cooperative tactical decision making is the core of the UAV combat system. How to grasp the key information in the complex and changeable battlefield situation and make the correct decision has a huge impact for the result of air-combat. The goal of UAV autonomous decision-making is to make the right choice based on the battlefield information, so that we gradually gain the advantage.

The traditional UAV decision algorithm, such as differential game algorithm and matrix countermeasure algorithm, which ideas is to simulate the pursuit process, the disadvantage of traditional algorithm is the fixed of the role that is different with the realistic combat situation. In recent years, the artificial intelligence technology has achieved the great development, and many of them, such as genetic algorithm, particle swarm optimization algorithm, neural network and the deep learning, has been used to solve the UAV tactical decision making problem, but these algorithms need much time to get the training data, which are not consistent with the real time requirement.

In this paper, with the considering of real-time and reasonable requirements, we proposed a method which uses the Plan Goal Graph to solve the UAV air-combat autonomous decision, combined with the existing manned aircraft control model. Meanwhile, the heuristic knowledge in double-vehicle domain was introduced to help the UAV to make the reasonable maneuvering decision.

II. Plan Goal Graph

So far, the behavior of the machine has not been widely recognized, but it is undeniable that there are some details of the knowledge expression which is achieved by people. The information and behavior of this world have own rules, the intelligence is a dynamic system, it extracts the rules from the world information and put in knowledge library, forming their own prior knowledge. The intelligence system can use knowledge library to make the plan and achieve the goal by carry out the plan. Plan Goal Graph is a kind of graph data structure which used to express the heuristic knowledge.

In the field of air combat, plan goal graph can be used to express the knowledge of UAV air-combat. There are two type of nodes in the data structure of plan goal graph, the first one is goal node, which is used to represent the desire to achieve, the another one is plan node, which is used to express the operation can be selected to complete the goal of father node. The top node of plan goal graph is the abstract goal which represent the highly abstract and subjective intention. Each descending level represents the target becomes more and more specific and executable, the base of the plan goal graph structure represents the atom action which can be directly executed by pilots or the aircraft, the higher task all can be resolved into atom node which can be directly execute. Figure 1 shows a general PGG data structure diagram.

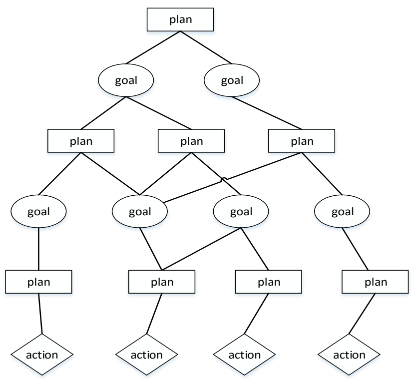

Figure 1. PGG data structure

The rectangular node in the PGG diagram is planning node, the oval node in is goal node, the diamond-shaped node in the bottom is atom node which can be directly execute. The link between different nodes indicates that the constraint conditions are satisfied, and only the parent node can be linked

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to the child node. PGG is a tree structure that contains the process of a high level of abstract task gradually decomposed into executable atom task. The process of PGG planning is the cutting of the PGG diagram. The state of the system is changed step by step through the finish of the atom node. Process can be represented like figure 2.

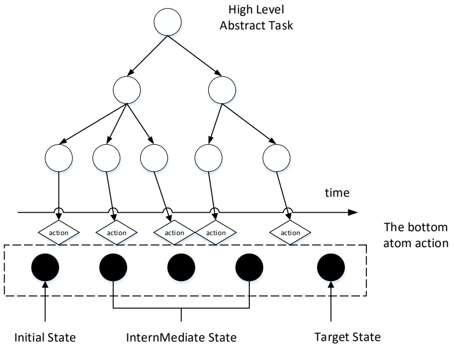

Figure 2. PGG state change

As a task planning method, the principle of the PGG algorithm can be describe like table 1.

TABLE I. PGG ALGORITHM DESCRIPTION

Step	Planning produce of PGG algorithm
1	Enter the high-level abstraction task, get the first level decomposition of the task T
2	Execute goals in the decomposition of the T in the order of Goal-1,2,3….,n
3	If the Goal-x is atomic task, then directly execute with the instance parameters, and return the results of execution. Else if the Goal-x cannot be executed, then return false. Go to step 2.
4	If the Goal-x is a composite task, then select one of decomposition method M of the Goal-x.
5	Replace Goal-x with M.
6	Go to step 2.

III. AUTONOMOUS TACTICAL DECISION MAKING

A. Autonomous Decision Making structure

In the modern air-combat, the aircraft is becoming more and more automated, integrated and intelligent, more and more information also need to be handled by pilot, but many of them cannot be used directly, so it is important to help pilots to handle the information and make the tactical decision. Autonomous decision-making system can help pilots execute various types of tasks such as situation evaluate, task planning and tactical decision, etc.., at the same time, it can also respond to emergencies and understand what the pilot wants to do, this will emancipate pilots from complex information process and make them focus on the high tactical level.

The role of pilots in air combat is decision maker, they can make the reasonable decision through the two sides information they known which is based on the experience and tactical rules they grasped. The goal of the decision is to gain some advantage and attack enemy. As the intelligent and unmanned future direction of the air-combat, the decision maker will be replaced by the autonomous decision making module. Autonomous decision making module need to have the ability to make the decision without the help of pilots, the decision-making basis is the experience knowledge and tactical rules. Through the detection and monitoring, it will have the ability to deal emergencies. The UAV will get the exact maneuver commands through the autonomous decision-making module which can make the UAV complete the task.

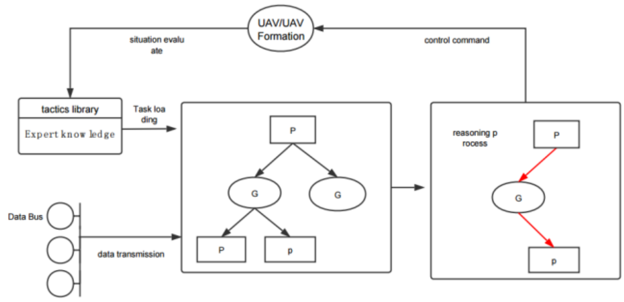

Figure 3. Tactical decision making structure based on PGG

Figure 3 is the control structure of the UAV whose decision-maker was replaced by PGG autonomous tactical decision module, UAV choose the exact tactic based on the situation information when loads the initial task, and the tactic represents the pilot subjection intention, then the control module will load the PGG decomposition of the tactic. The data bus was used to load the situation information of both two sides, such as the position information and weapon information, etc…,there will be a series of atomic action after the choose of PGG algorithm. The autonomous tactical decision-making module will send a series of maneuver commands to UAV.

B. Domain Heuristic Knowledge

We introduce several common offensive and defensive tactics, offensive and defensive tactics are also divided into cooperative and non-cooperative. In the cooperative offensive tactics, the two vehicle of mine should have the same mobility and attack ability that they can qualify for the attack task and the swap of role. In non-cooperative offensive tactics, it can be looked as 1v1 air-combat in a period of time. If the ability of enemy lies between captain and follower and the target cannot be destroy in the first time, then the UAV of mine will be noticed by enemy, we should take the retreat tactics to protect our UAV in this disadvantage situation. Table 2 lists several common tactics.

TABLE II. SOME COMMON 2V1 TACTICS

	Image Numbers	Image size
Offensive	Head-on Attack	Main Attack and Cover
	Double Flank	Hidden contact enemy
Defensive	Defensive Division	The combination of extended
	Lure the enemy deep	

Here are some of the 2V1 formation tactics:

Head-on Attack: The target entry angle is in the 30° range of our UAV, the detection ability and motor ability of mine are more strong than enemy, when this two conditions are satisfied, we can take this tactic. In the air-combat, if the target is in high position, then we should attack in the low, on the contrary, we should attack in the high position. Head-on attack should consider about the both sides relative position, detection ability and motor ability, etc…

Double Flank: Double flank tactic is used in the over-the-horizon (OTH) condition, the UAV of mine go around to the back of enemy and carry out the attack, the tactic is suitable for the situation that the detection ability and maneuver ability of mine are all not as good as enemy, the advantage of this tactic is to avoid the enemy's power and make the full use of position advantage, grasping the attack opportunity in the front of enemy

Defensive Division: In the process of air-combat, our UAV may loss the advantage of the attack goal and be pursued by the enemy, we lost the initiative of the air-combat. At this time, we should take the defensive division tactic, the two UAV of mine should separate at first and then get together, the enemy can only catch up one of our UAV, and another UAV of mine can look for the attack opportunity. Defensive division tactic belong to the hybrid tactic which include defense and offence.

Lure the enemy deep: The tactic can be used if the maneuver ability of follower is better than captain and enemy, only in this condition can ensure that the follower can quit the battlefield whenever it wants. The follower comes into the attack range of enemy and then adjusts its direction. At the same time, the captain look for the opportunity to break the enemy. Attacking enemy unawares is the biggest advantage of lure the enemy deep tactic.

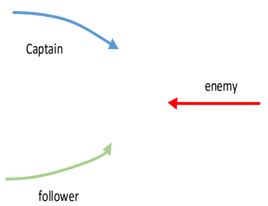

Figure 4. Head-on Attack

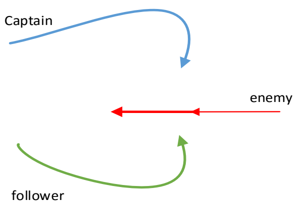

Figure 5. Double Flank

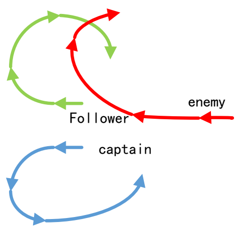

Figure 6. Defensive Division

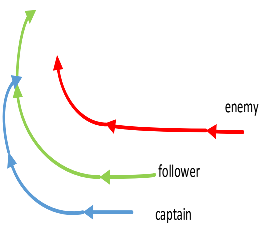

Figure 7. Lure the Enemy Deep

C. The Evaluating model of PGG Planning

PGG planning is a task decomposition of the abstract task which represents the subjective intention of pilots. The decomposition is implemented based on PGG data structure knowledge and the precondition of decomposition is air-combat situation. The high-level abstract task can decomposed into a series of atomic action, the process of decomposition make turn subjective intention atomic action which can be execute by UAV, the main operation of the decomposition process is selection, the parent node need to select a node from its sub node to achieve the goal.

In the process of PGG planning, if there are multiple nodes which can accomplish the parent task, the PGG planning algorithm should cut the sub node according to the tactical rule, delete the sub node which was not adapt to the current situation, after this, if there was only one sub node left, the node was the result of this selection and the cut was the result of the situation evaluate.

If the result of the cut was not the only sub node, the PGG planning algorithm should value the cost of left nodes and choose the minimum cost node. Assumed that every step of PGG planning can be represent by Si, so we can use vector S to represent all the selection in the process of planning like this:

$$\vec{S} =< S_1, S_2, \dots, S_i, \dots, S_n, > \quad (1)$$

The final result of the planning algorithm is a sequence atomic actions, the goal of the sub task is to satisfy the goal of the parent node and different sub nodes have different cost, assume the sequence of atomic action is:

$$\vec{C} =< C_1, C_2, C_3 \dots, C_i, \dots, C_n > \quad (2)$$

The cost of every action is $\mathrm{Cost}(C_i)$.

So, the cost of the action sequence which is represented by formula (3),

$$\mathrm{f}(\vec{S}) = \sum_{i=1}^{m} Cost(C_i) \quad (3)$$

The target is to find the optimal solution in the residual task space which makes the minimum cost of the parent task. Besides, the process of decision-making needs some benefits evaluation as the standard of choice, reasonable choice can bring advantage to us. In the air-combat, suppose that the hit rate of different attack way is P_{hit}, the rate of target approach is Pin, the rate of our UAV damaged is P_{break}, the value of our UAV is V_{own}, so the value of V_{own} is decided by UAV value and the weapon value,

$$V_{own} = V_{uav} + num * V_m \quad (4)$$

V_{uav} is the value of the UAV, num is the weapon number UAV bring, V_m is the value of the weapon.

Assume that the value of the enemy is V_{target}, the rate of enemy fight back is CA, the rate of enemy damaged is described as follow:

$$P_{damage} = P_{hit} * P_{in} * \mathrm{H} \quad (5)$$

H is enemy damage coefficient, in other words, it means the ability to stay safe under the attack.

The benefits to attack the enemy is described as follow:

$$X = V_{target} * P_{damage} \quad (6)$$

The rate of our UAV damaged is:

$$P_{destory} = P_{break} * CA \quad (7)$$

The cost of our UAV broken is described as follow:

$$\mathrm{Y} = V_{own} * P_{destory} \quad (8)$$

So the cost of attacking enemy is described as follow:

$$\mathrm{Cost} = \mathrm{Y} - \mathrm{X} \quad (9)$$

IV. SIMULATION EXPERIMENT

We conducted simulation experiments in the 2V1 air-combat scenario, 2 our UAV and 1 enemy UAV, experiment situation: the two UAV of mine take off and cruise when they reach designated height. The UAV evaluates the situation when they are cruising and choose reasonable tactic according to the combat situation when they find enemies. In our scenario, there are two UAV of mine and one UAV of enemy and the detection ability of enemy is better than our vehicle, so it adapts to use the double flank tactic. After the attack, the UAV of mine will estimate the damage and quit the battlefield, return to the airport. The PGG data structure diagram of double flank tactic as shown in the figure 4.

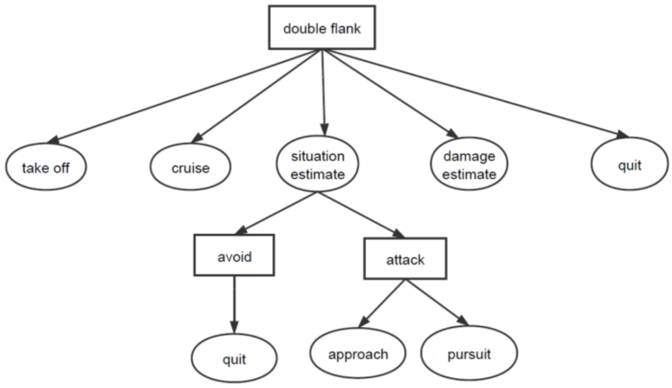

Figure 7. Double flank PGG data structure

The specific parameters of our UAV and enemy UAV are shown in the table 3 and table 4.

TABLE III. UAV PARAMETERS

Parameters	Our	Enemy
Radar horizontal scanning angle	40°	40°
Radar vertical scanning angle	30°	40°
Radar detect distance(km)	150	200
Missile number	3	1
Max attack distance(km)	50	70

TABLE IV. UAV INITIAL STATE

Parameters	Captain	Follower	Enemy
Longitude	-114.39°	-114.24°	-114.04°
Latitude	36.92°	36.928°	37.7618°
Height(m)	5000.14	5000.26	4999.9
Speed(m/s)	312	320	290
Direction	-33°	57°	-75°

In the double flank attack simulation experiments, we get the results shown in the figure 4, we can find the movement tracks of both sides. The process of attack can easily divided into 2 parts, the first part is making contact with the enemy, in this part, the UAV of mine need to bypass the detect range of enemy and flank from both sides. The second part is pursuit, the UAV of mine will speed up to catch the enemy and attack the enemy, but they need to adjust its direction firstly, if the enemy is in the range of attack, the UAV of mine will attack the enemy.

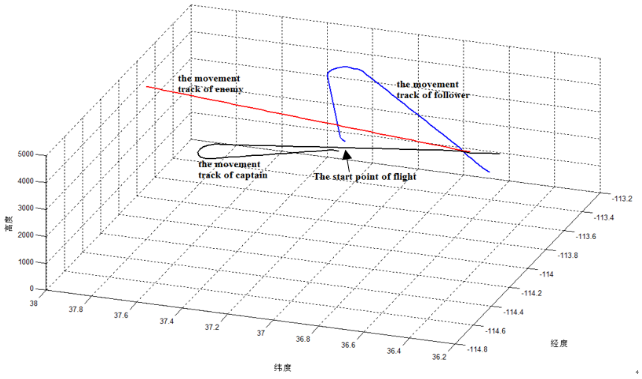

Figure 8. Simulation Result

The PGG planning results: two UAV of mine take off from airport and climb to the 5000 meters, in the process of cruise, they find one enemy UAV and their ability is less than the enemy in detection and mobility, so they choose double flank tactic, two UAV of mine move to the two sides of enemy and avoid the detection of enemy, after they reach the back of enemy position, they turn around and catch up the enemy, from the simulation result we can find the attack point of captain is (-114.245,36.398,5000), the attack point of follower is (-114.227， 36.396， 5000), after they get advantage position and the enemy is in the range of attack, they will choose to attack the enemy, then they will estimate the damage and quit the battlefield, return to airport.

The sequence of action is shown in the table 5 and table 6, which represent the sub task of captain and follower respectively.

TABLE V. THE CAPTAIN PLANNINGSEQUENCE

Maneuver	Position	Time	Instance parameter
Take off	(-114.39, 36.87,0)	0:0:0	(-114.39, 36.87,5000)
Cruise	(-114.39, 36.87,5000)	0:4:28	NULL
Approach	(-114.39, 36.87,5000)	0:6:05	(-114.64,37.38,5000)
Pursuit	(-114.47,37,36,5000)	0:9:40	(-114.24,36.39,5000)
Attack	(-114.24,36.39,5000)	0:15:42	1
Estimate	(-114.24,36.39,5000)	0:16:02	NULL
Quit	(-114.12,36.40,5000)	0:22:07	(-114.39, 36.87,0)

TABLE VI. THE FOLLOWER PLANNING SEQUENCE

Maneuver	Position	Time	Instance parameter
Take off	(-11429, 36.88,0)	0:0:0	(-114.29, 36.88,5000)
Cruise	(-114.29, 36.88,5000)	0:4:28	NULL
Approach	(-114.39, 36.88,5000)	0:5:48	(-113.65,37.22,5000)
Pursuit	(-113.59,37.12,5000)	0:9:26	(-114.22,36.39,5000)
Attack	(-114.22,36.39,5000)	0:15:42	1
Estimate	(-114.22,36.39,5000)	0:16:02	NULL
Quit	(-114.23,36.41,5000)	0:22:07	(-114.29, 36.88,0)

V. CONCLUSION

In this paper, we have used the Plan Goal Graph algorithm in the autonomous tactical decision making of UAV air-combat, proposed the decision-making structure based on the Plan Goal Graph, and summarized several common tactical rules in the air-combat field. It can be seen from the simulation results that the PGG algorithm can solve the problem of air-combat task planning very well, at the same time, the PGG algorithm can meet the air-combat requirements of the effectiveness and real-time. The method can support all the air-combat scenario through the expansion of heuristic knowledge. On the basis of reasonable task decomposition, it can effectively solve the task planning of other scenario, so the method can also meet the requirements of adaptability and expansibility.

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