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Game Intention Analysis and Optimal Decision Methods: A Survey

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***Abstract*—This paper provides a comprehensive review of the research on intention analysis and optimal decision-making methods for group games in the field of air combat. Air combat is considered as a complex game process involving multiple participants, stages, and incomplete information. It encompasses three key aspects: intention analysis, mission planning, and autonomous decision-making. The paper presents an overview of the principles, methodologies, and applications related to intention representation and recognition methods, competition and cooperation models, as well as optimal decision generation algorithms in group games. Furthermore, future research directions are proposed including the integration of optimization algorithms with learning algorithms, exploration of large-scale optimization techniques, and investigation into leveraging deep learning approaches for modeling, prediction, and optimization in crowd games.**

***Keywords*—group games, intention analysis, mission planning, autonomous decision-making**

I. INTRODUCTION

Air combat is a highly complex and uncertain antagonistic activity in which both sides try to achieve their goals through various means and strategies. In such an environment, how to effectively analyze the enemy's intention and predict the enemy's possible actions according to the intention is an important problem to improve the effectiveness and chances of victory. However, due to the characteristics of high dynamic, high complexity and high dimension of the air combat battlefield, it is difficult to accurately identify and predict the enemy's intention, and it also brings challenges to the formulation of appropriate combat plans and decisions. Therefore, how to use the existing battlefield information and historical data to construct an effective group game intention analysis and optimal decision-making method has become a hot and difficult problem in the field of air combat research.

Group game intention analysis and optimal decision method is a model and method of air combat based on group game theory, which regards air combat as a game process with multi-participants, multi-stages and incomplete information. The method mainly includes three parts: intention analysis, task planning and autonomous decision making. Intention analysis refers to the analysis and processing of existing battlefield information (such as the position, speed, heading, etc.) and enemy historical combat data (such as enemy aircraft type, weapon performance, combat mode, etc.), so as to infer the current or future actions or targets that the enemy may take. Mission planning refers to formulating a reasonable battle plan according to the current battlefield situation and the mission objectives of the own side (such as attacking enemy targets, protecting their own targets, retreating, etc.), including assigning roles, tasks, and routes of their own aircraft. Autonomous decision-making refers to the process of executing a mission, based on the enemy information obtained in the intention analysis and the information elements injected from the outside (such as commander's instructions, communication from other aircraft, etc.), through the analysis of the battlefield situation of both the enemy and me, their own state, the enemy's intention and other factors, to decide the optimal strategy under the current situation, such as acceleration, turning and launching of weapons. The goal of this method is to maximize the benefits of one's own side through reasonable and efficient decision-making and command, seize the advantage and occupy the position in the game process, and finally win.

This paper aims to review the group game intention analysis and optimal decision-making methods. First, it introduces the characteristics of the air combat battlefield and the basic concepts of the air combat model. Then, it analyzes the group game intention representation and identification methods, the group game model of antagonism, competition and coordination, and the group game optimal decision generation algorithm. The principle, method and application of this method are introduced and analyzed in detail. Finally, the advantages and disadvantages of this method and the future development trend are summarized and prospected. It is hoped that this paper can provide some useful reference and enlightenment for the field of air combat research.

II. THE CHARACTERISTICS OF AIR COMBAT BATTLEFIELD AND THE BASIC CONCEPT OF AIR COMBAT MODEL

A. Characteristics of Air Combat Battlefield

Air combat is a kind of confrontation activity in the air, which involves a variety of aircraft, weapons, sensors, communication and other elements, constituting a highly complex and uncertain battlefield environment. The air combat battlefield has the following notable characteristics:

High dynamic: Both the enemy and the US in the air combat battlefield have high-speed movement and maneuvering capabilities, resulting in rapid battlefield situation changes, frequent information updates, and urgent decision-making time, while also increasing the uncertainty of the enemy's intentions and actions.

High complexity: The air combat battlefield involves a variety of aircraft, weapons, sensors, communication and other elements, among which there are complex interactions and effects, such as coordination, interference, stealth, interception, evasion, damage, etc., between the aircraft, detection, identification, tracking between the sensors, transmission, encryption, interference, etc. The combination and changes of these elements make the air combat battlefield highly nonlinear and random.

High Dimension: The air combat battlefield is a three-dimensional space, both sides can move and attack in any direction, but also need to consider the time dimension and information dimension. The time dimension refers to the occurrence and duration of various events in air combat, such as the take-off, arrival, turn and launch of aircraft, the launch, flight and hit of weapons, the opening, closing and scanning of sensors, and the sending, receiving and delay of communications. Information dimension refers to the acquisition, processing, transmission and utilization of various information in air combat, such as the position, speed, heading and other state information of the enemy and us, the type, performance, intention and other attribute information of the enemy and us, and the evaluation information of the battle plan, strategy and effect of the enemy and us.

B. Basic Concept of Air Combat Model

Air combat model is a mathematical tool to abstract and describe the process of air combat. It can be used to analyze various problems in air combat, such as enemy intention analysis, mission planning, autonomous decision-making, etc. The air combat model mainly includes the following basic concepts:

Air combat participant: An air combat participant is an entity that is directly or indirectly involved in counteraction activities in air combat, such as aircraft, weapons, sensors, communications, etc. Each participant has its own attributes (such as type, performance, etc.) and state (such as location, speed, etc.), and can make decisions and act based on its own or others' information.

Air combat targets: Air combat targets are entities that need to be attacked or protected in air combat, such as enemy aircraft, own aircraft, ground targets, etc. Each target has its own attributes (such as type, value, etc.) and status (such as location, threat, etc.), and can be attacked or protected by both enemy and foe.

Air combat strategy: Air combat strategy refers to a series of decisions and actions taken to achieve a certain goal in air combat, such as attack, defense, retreat, etc. Each strategy has its own effects (such as losses, gains, etc.) and conditions (such as information, resources, etc.), and can be adjusted according to battlefield situation and objectives.

Air combat game: Air combat game refers to a kind of antagonistic activity, such as pursuit, escape, interception, etc. carried out by both sides in air combat in order to achieve their respective goals. Each game has its own rules (such as players, goals, etc.) and outcomes (such as wins and losses, gains, etc.), and can evolve according to the strategies and actions of both sides.

III. RESEARCH ON GROUP GAME INTENTION REPRESENTATION AND RECOGNITION METHODS

As a powerful machine learning technique, deep learning is able to learn useful information from complex and non-linear data, enabling intelligent agents to effectively adapt to complex and dynamically changing operational environments. Existing research usually combines deep learning technology to mine valuable information from combat data in order to explore the possible direct or indirect relationship between combat data and intent information. Table 1 classifies the representation and recognition methods of group intention in group game from three aspects: group intention formalization, group intention recognition model and Intention authenticity evaluation model, and analyzes the commonly used techniques, advantages and disadvantages of each type of method.

Table 1. The group game intention representation and recognition methods

Methods	**Group intention formalization**	**Group intention recognition**	**Intention authenticity evaluation model**
Details	probabilistic graph model: 1. the combination of dynamic Bayesian network and sequential Bayesian network 2. uses the experience to build a model base, and then carries out feature extraction based on actual scenes.	deep learning: 1. a neural network model composed of contrastive predictive coding model, variable length Long Short-Term Memory (LSTM) model and attention weight distributor. 2. an air combat intent recognition model based on deep neural network by improving the activation function and parameter adjustment algorithm of deep confidence network 3. two-way communication mechanism and attention mechanism	the joint tree inference algorithm: 1.evaluate and predict the current situation
Disadvantages	1. the accuracy of intent recognition low and makes it difficult to determine false intent 2. has not considered how to effectively use the intent characteristics of successive moments to support decision making		
Future research	1. combining various data sources such as vision, voice and sensors 2. the application of deep learning in group game intent representation and recognition will be explored more 3. study more deeply the authenticity of intention 4. focus on adaptive learning methods to mine potential patterns and features		

A. Group Intention Formalization

In terms of group intention formalization, the current research on group intention formalization at home and abroad focuses on probabilistic graph model, which calculates the probability of enemy UAV's air combat intention through prior knowledge such as known air combat situation and fighter state information. Aiming at the air combat environment with constantly changing state information, An *et al.* [1] uses the combination of dynamic Bayesian network and sequential Bayesian network to deduce the tactical intent of enemy UAS. Xing *et al.* [2] uses the experience of experts in the field of air warfare and combat commanders to build a model base, and then carries out feature extraction based on actual scenes.

B. Group Intention Recognition Model

In terms of group intention recognition model, the main research work at present is deep learning method. In view of the incomplete and imperfect nature of battlefield situation, Wang *et al.* [3] proposed a neural network model composed of contrastive predictive coding model, variable length Long Short-Term Memory (LSTM) model and attention weight distributor. It can significantly improve the efficiency, stability and reliability of battlefield intent recognition. However, the model needs to package the features of time series before training, so it cannot be easily trained end to end. Ying *et al.* [4] designed an air combat intent recognition model based on deep neural network by improving the activation function and parameter adjustment algorithm of deep confidence network. Finally, through simulation, the proposed model has a high recognition rate, but this method can only deal with the current moment and cannot deal with all time periods. Considering that the event situation information of the battlefield is usually imperfect, two-way communication mechanism and attention mechanism can also be added to the air combat intention feature recognition [5], which mainly constructs the air combat intention feature set through hierarchical methods, encodes the features into digital time series features by using word embedding, and then uses two-way gated recurrent neural network to conduct deep learning of air combat features. The attention mechanism is introduced to assign feature weights adaptively to improve the accuracy of combat intention recognition of aerial targets.

C. Intention Authenticity Evaluation Model

In terms of group intention authenticity assessment model, there are few relevant studies at present, and the main work focuses on using the joint tree inference algorithm to evaluate and predict the current situation in the complex battlefield environment [6], but the accuracy and practicability are insufficient. Based on this, this project intends to study the authenticity assessment model of group intention through feature database and data mining technology. On the one hand, behavioral pattern and behavioral feature database are established to extract and analyze the characteristics of false behaviors. On the other hand, by utilizing machine learning and data mining techniques, reliability assessment models are constructed to distinguish between true and false intentions caused by different behaviors.

D. Summary and Future Outlook

The existing research mainly focuses on the construction of intention recognition model in the scenario of antagonism between us and the enemy. However, for complex group game scenarios, the one-sidedness of intent information detected at a single moment makes the accuracy of intent recognition low and makes it difficult to determine false intent. Current research has not considered how to effectively use the intent characteristics of successive moments to support decision making.

At present, the research on the representation and recognition of group game intention in denial environment mainly focuses on multi-modal data fusion, deep learning and adversarial learning. Firstly, in the future, multi-modal data fusion will be carried out by combining various data sources such as vision, voice and sensors to comprehensively describe the behaviors and intentions of group members, thus improving the accuracy and reliability of intention recognition. Secondly, the application of deep learning in group game intent representation and recognition will be explored more in the future. For example, various advanced neural network models will be used to extract and represent group intent information, and operational intent prediction models will be designed to adapt to complex and dynamic denial environments. Thirdly, through the combination of game theory and reinforcement learning, the decision-making process and strategy selection in group behavior are modeled, so as to better understand group intention and behavior. From the second, in the denial environment, the enemy will take various strategies to interfere and mislead. In the future, the authenticity of intention will be studied more deeply, and adversarial learning methods will be explored to improve the reliability of intention recognition model. Finally, in order to enable the model to adjust and update autonomously according to the data, the future will also focus on adaptive learning methods to mine potential patterns and features from unlabeled data through unsupervised learning to improve the generalization ability of the model.

In general, the research on group intention representation and recognition will pay more attention to multi-modal data fusion, the application of deep learning methods, the combination of reinforcement learning and game theory, and the enhancement of adversarial intention recognition, so as to provide more effective support for unmanned cluster operations and decision-making.

IV. The Group Game Model of Antagonism Competition and Coordination Cooperation

With the deepening of research, group game has been widely used in various fields. In recent years, the rapid development of machine learning and artificial intelligence has brought new opportunities for group game research. Existing research usually uses machine learning methods to explore the competition and coordination of intelligent systems such as multiple unmanned aerial systems and rescue robots, as shown in Table 2. This section mainly elaborates the research status of group game model from two aspects: group antagonism game model and coordination cooperation group game model.

In terms of group adversarial game model, Jang *et al.* [7] adopts distributed control method to control UAVs, which solves the problem that UAVs cannot fully play their individual performance due to centralized control, which leads to high requirements for UAVs' communication ability and central node's computing power. Aiming at the problem of offensive and defensive confrontation of UAVs, Zixuan e*t al.* [8] uses the depth determination strategy gradient method of multiple UAVs and the framework of centralized training and distributed execution, so that unmanned clusters can complete cooperation without complete communication between clusters, effectively learn decision control strategies, and extend this framework to near-end strategy optimization [9].

Table 2. The group game model of antagonism competition and coordination cooperation

Game Mode	Group Adversarial Game Model	Cooperative Group Game Model
Related work	distributed control method	the auction-based market model
	depth determination strategy gradient method and the framework of centralized training and distributed execution	a distributed coordination model
	extend the framework of centralized training and distributed execution to near-end strategy optimization	a game theory autonomous decision framework to solve the cooperative task assignment problem of multi-agent groups
Future research	combine deep learning with reinforcement learning perform pay more attention to modeling uncertainty	integrate deep learning and reinforcement learning pay more attention to distributed decision-making and communication
Disadvantages	1. ignore the complexity and individual differences of the model 2. a certain degree of error in the prediction results of the model 3. ignore the differences between individuals	

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A. Coordination and Cooperation Group Game Model

In terms of its own cooperative group game model, the auction based market model in Jiao *et al.* [10] can maximize the social welfare of blockchain networks and provide effective strategies for cloud/fog computing service providers. For communication with limited competition, Lujak [11] designed a distributed coordination model to develop a new coordination control for multiple non-holonomic robots in a competitive manner, where only the winner would get the task and be activated to move towards the goal. Considering the selfishness of cooperative agents, Li *et al.* [12] proposes a game theory autonomous decision framework to solve the cooperative task assignment problem of multi-agent groups, and ensures that agents with social inhibition converge to Nash stable division in polynomial time through decentralized algorithms. Due to the imbalance of utility in the history of alliance formation, Chang [13] adopts the principle of non-reducing utility distribution to encourage intelligent agents to expand alliance to obtain greater overall and individual benefits, which has the advantages of simplicity and efficiency.

B. Summary and Future Outlook

Although the existing research is usually based on mathematical formalization methods, the structure and parameter setting of the model are highly interpretable, but the complexity and individual differences of the model are ignored. The existing group game model is usually based on the theoretical assumptions of the experimental environment, which may not fully and accurately reflect the real and complex strategies of both sides, resulting in a certain degree of error in the prediction results of the model. Moreover, the group game model often regards the group members as homogenous individuals, ignoring the differences between individuals. This can lead to a partial understanding of real group behavior.

At present, the research on intent-based group games mainly focuses on game, deep learning and reinforcement learning. On the one hand, with the development of artificial intelligence, automation technology and communication technology, the research of group adversarial game is also deepening. Considering that deep learning and reinforcement learning perform well in dealing with complex environments and decision problems, future research can combine these two methods to improve the predictive model of intelligent agent behavior and intention information, so as to achieve decision optimization of adversarial game models in complex environments. In addition, the adversarial game in reality is often accompanied by uncertainty and incomplete information, and future research will pay more attention to modeling uncertainty in order to better adapt to the complex and dynamic environment. On the other hand, group cooperative game is also developing, which has important applications in multi-agent systems. In order to enable the model to adapt to complex and changing environments and tasks, the future cooperative game model will integrate deep learning and reinforcement learning and other technologies to learn from real game scene data and continuously optimize cooperative decision-making, so as to improve the intelligence of autonomous decision-making in complex scenes. In addition, with the development of the Internet of Things and 5G technology, future cooperative game model research will pay more attention to distributed decision-making and communication, and multiple intelligent agents can negotiate and cooperate through efficient communication means to achieve more complex task goals.

In general, the adversarial game in the real environment usually has uncertainty and incomplete information. Therefore, future research will pay more attention to the modeling of uncertain environment and distributed decision-making and communication, so that the model can better adapt to the complex and dynamic environment.

V. GROUP GAME OPTIMAL DECISION GENERATION ALGORITHM

With the vigorous development of artificial intelligence technology, traditional optimization algorithms such as genetic algorithm and ant colony algorithm have limitations when dealing with complex scenes. In recent years, deep learning and reinforcement learning have been widely used in various fields, and they also provide new ideas for optimal decision generation methods in group games. In addition, new technologies such as transfer learning and meta-learning have also begun to be applied to group games, and are committed to solving problems such as sample scarcity and domain migration. In Table 3, the common algorithms are analyzed and summarized. This paper mainly discusses the research status of optimal decision generation algorithm in group game from three aspects: dynamic programming, evolutionary algorithm and reinforcement learning.

Table 3 Group game optimal decision generation algorithm

Optimal algorithm	Dynamic programming	Evolutionary algorithm	Reinforcement learning
Application field	a virtual machine allocation method DP-VMPA to maximize social welfare	optimize resource allocation strategies to maximize total seller profits	continuous landing
	a real-time scheduling method of heterogeneous resources based on stochastic dynamic programming and N-person non-cooperative game to reduce operating costs in energy scheduling management	the strategy optimization of mobile edge servers to find the optimal resource allocation scheme	UAV trajectory optimization
Disadvantages	high computational complexity	easy to fall into local optimality	lack the fusion of intelligent agent intention information.
Future research	1. optimization algorithms and learning algorithms can be integrated 2. study large-scale optimization algorithms 3. explore how to use deep learning technology to model, predict and optimize group games		

A. Dynamic Programming Optimal Strategy

In dynamic programming, small scale decision problems can be solved efficiently by establishing state transition model and defining appropriate objective function. For example, in the optimal allocation of virtual machine resources, Geng *et al.* [14] proposed a virtual machine allocation method DP-VMPA based on dynamic programming to maximize social welfare. Park *et al.* [15] explored the role of dynamic programming in energy scheduling management, and adopted a real-time scheduling method of heterogeneous resources based on stochastic dynamic programming and N-person non-cooperative game to reduce operating costs in energy scheduling management. These studies provide important theoretical support for the application of dynamic programming algorithms in the generation of optimal decisions in group games. However, as the scale of the problem increases, the computational complexity of dynamic programming algorithm increases exponentially, resulting in high computational overhead.

B. Evolutionary Algorithm Optimal Strategy

In terms of evolutionary algorithms, by establishing competition and genetic operations between individuals with different strategies, the strategy is gradually optimized and the optimal solution is found. For example, in the cloud services market, evolutionary algorithms are used to optimize resource allocation strategies to maximize total seller profits [16]. In addition, evolutionary algorithms have also been applied to the strategy optimization of mobile edge servers to find the optimal resource allocation scheme [17]. However, although evolutionary algorithms have certain advantages in solving optimal decision generation problems in group games, for problems with high and continuous space, they may fall into local optimal solutions and cannot guarantee global optimal solutions.

C. Optimal Strategies for Reinforcement Learning

In reinforcement learning, the interaction between the intelligent agent and the environment is used to optimize the strategy through learning confrontation and cooperation, so as to achieve the optimal decision. At present, compared with traditional optimization algorithms, reinforcement learning methods have the advantages of empirical learning, processing complex scenarios and adaptive learning to make optimal decisions, and are widely used in group games. For example, in the field of unmanned clusters, reinforcement learning has been applied to the optimal strategy for continuous landing [18] and UAV trajectory optimization [19]. Gong *et al.* [20] developed an intelligent decision algorithm based on reinforcement learning to enable UAVs to exchange information, negotiate task assignment, and jointly complete related task objectives such as path planning.

In existing studies, compared with dynamic programming algorithms with high computational complexity and evolutionary algorithms that are easy to fall into local optimality, reinforcement learning algorithms have good performance in autonomous learning and optimization strategies in interaction with the environment. However, the current group game optimal decision generation algorithm based on reinforcement learning lacks the fusion of intelligent agent intention information.

At present, the research of optimal decision generation algorithm in group game mainly focuses on distributed algorithm, game theory and deep learning. First of all, with the increasing complexity of group game problems, in order to achieve real-time solution of optimal decisions, optimization algorithms and learning algorithms can be integrated in the future, so as to quickly find the optimal or near-optimal decisions in complex environments. Secondly, the scale of group game problems is also expanding. In order to deal with the huge state and action space in large-scale group game, large-scale optimization algorithms will be studied in the future, and hardware resources such as modern computing clusters will be fully utilized, so as to make it possible to solve the optimal decision in large-scale game. Finally, in order to improve the accuracy of optimal decision making, we will explore how to use deep learning technology to model, predict and optimize group games, so as to realize intelligent agents that can cope with complex and changeable game situations.

In general, the group game optimal decision generation method has important guiding significance in military scenarios. Future research will closely combine reinforcement learning and optimization algorithms and other technologies to pay more attention to real-time decision making, large-scale scenarios and complex and changeable situations, so as to help gain advantages in complex battlefield environments.

VI. Conclusion

This paper reviews the intention analysis and optimal decision method of group game, which is a model and method of air combat based on group game theory. It regards air combat as a game process of multi-participant, multi-stage and incomplete information, which mainly includes three parts: intention analysis, task planning and autonomous decision. This paper first introduces the characteristics of the air combat battlefield and the basic concepts of the air combat model, and then introduces and analyzes the principle, method and application of the method in detail from three aspects: the group game intention representation and identification method, the group game model of opposing competition and coordinating cooperation and the group game optimal decision generation algorithm. Finally, the advantages and disadvantages of this method and its future development trend are summarized and prospected.

This paper hopes to provide some useful reference and enlightenment for the field of air combat research and lay a foundation for the further development of this field by summarizing the group game intention analysis and optimal decision methods.

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