Construction of Environmental Factor Model Based on Agent

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Abstract: This paper explores the ability and expression form of the combination of intelligent agents and environmental element modeling from a GIS perspective. Firstly, the complexity of environmental element data is analyzed, and the current spatial-temporal model of environmental data organization in the geographic information field is reviewed, and the full-process operation of the interaction between intelligent agents and the environment is proposed. Secondly, to address the disadvantage of the insufficient storage, analysis, and expression capabilities of intelligent agents for environmental element data, an environmental modeling framework based on spatial grid division applicable to the entire space range is established. By further extending the object-oriented thinking and fully leveraging the expression mechanism of the grid body for internal environmental element attributes and element changes, it is conducive to the efficient use of intelligent agent perception information and computational analysis, scenario deduction and decision support. Finally, through task-driven case studies in the military domain, the effectiveness of the intelligent agent-based environmental element organization and expression model is demonstrated, providing a reference for the wider application of intelligent agent technology in the geographic information field.

Keywords: intelligent agent, environmental elements, grid body objects, model application

1 INTRODUCTION

With the development of artificial intelligence technology and complex theoretical sciences, research on application fields based on agent systems has become a hotspot. An agent is a computational entity that resides in a specific environment, can continuously and autonomously exert its functions, possesses basic characteristics such as reactivity and proactivity, as well as behavioral abilities such as mobility and communication[1]. In the GIS (Geographic Information System) domain, agents can serve as independent geographic information systems capable of autonomous spatial data collection, analysis, and visualization, thus providing more intelligent geographic information services to humans. The extraction and storage of environmental element data using agents, integration and visualization of various typical environments, and realization of spatiotemporal environment simulation and assisted decision-making are of significant importance.

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2 INTERACTION BETWEEN AGENT AND ENVIRONMENTAL ELEMENTS

2.1 Analysis of complex environment and characteristics

Currently, single and dispersed environmental elements cannot support the construction of various complex environment application scenarios[2], nor can they satisfy various applications in the field of geographic information. Therefore, it is imperative to integrate complex typical environments, which are spatially represented as a unified description of space, atmosphere, land, and ocean environments. The space environment is not considered in this paper. Meanwhile, environmental elements have the following typical characteristics:

(1) Globality and high dynamics[3]. Environmental elements are constantly changing, and their data inevitably possess dynamic features, with different change frequencies according to their nature. Meanwhile, environmental elements exhibit global characteristics with strong correlation features among different elements.

(2) Multi-scale properties. Various environmental elements inherently possess spatiotemporal attributes, resulting in varying temporal resolutions and scales.

(3) Massiveness of environmental element data. Due to the numerous environmental elements, coupled with spatiotemporal variations, complex environmental elements change not only for any given four-dimensional spatiotemporal position, but also interact with other elements. With the development of artificial intelligence and various sensing and transmission technologies, the spatiotemporal resolution of environmental element data acquisition will become increasingly higher, with the data volume growing exponentially.

(4) Multi-source heterogeneity. Environmental element data is primarily categorized into site data, remote sensing data, and numerical simulation data according to their data sources and represented in various types such as vector data, raster data, and field data.

2.2 Analysis of existing GIS model of environmental factors

A comprehensive analysis of the environmental element characteristics reveals that the integration of environmental elements in a multi-dimensional, holistic manner is an inevitable trend. Therefore, a unified and efficient GIS data model is needed to support large-scale loading, multi-source heterogeneous data storage, standard scale constraints, and data relationships and changes expression. As the foundation for data organization, management, storage, and various application services, numerous research results on data models have been formed. According to the spatiotemporal data organization characteristics, they can be mainly divided into four categories: object-state-based spatiotemporal data models, object-oriented spatiotemporal data models,.event/process-based spatiotemporal data models, and data models based on spatiotemporal dynamic framework conceptual models. The data organization method based on the spatiotemporal dynamic framework conceptual model changes the previous research on single spatiotemporal objects or processes. It can provide a complete description and expression of spatiotemporal, attributes, and semantics for the internal mechanism and interaction of objects, continuously promoting the development of dynamic environment modeling[4]. Common spatiotemporal frameworks include geographic scene representation frameworks[5], spatial grid partitioning frameworks, and so on. Related GIS data models include GeoSOT Earth partitioning data models[6], and tiered structure combined with three-dimensional spatial grid models[7]. However, the above models have not started from a practical application perspective and cannot be directly incorporated into agents' environmental data collection, storage, spatiotemporal analysis, data mining, and rapid parameter adjustment. At the same time, the inadequacy in relationship expression limits the agents' real-time visualization and decision support for environmental features.

2.3 Role of Agent in Environment Modeling

The agent-based environmental modeling approach is an improvement over previous methods based on shape grammar and adversarial networks, incorporating both idealized environmental background presets and fully integrating the self-organizing features of the "design black box". By interacting with environmental features and setting tasks, agents use different sensors to collect various types of environmental feature data and store them in specific formats. Based on historical and current data, agents use actuators to perform analysis and communication, realizing environmental scene modeling as shown in Figure 1.

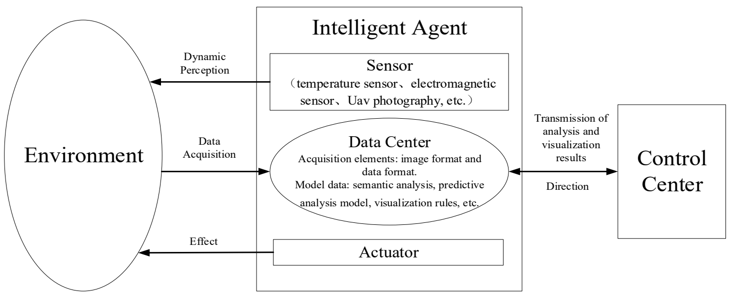

Figure.1 Interaction between Agent and Environment.

3 I CONSTRUCTION OF GRID MODEL

Agents can interact with the environment within a certain spatial range according to target tasks, perceive the spatiotemporal changes of various features, and carry out data storage, mathematical calculation, and analysis[8]. Therefore, it is necessary to combine it with GIS spatiotemporal data models to support efficient services and applications of the entire agent workflow. This paper considers the spatial characteristics of environmental features, data storage and processing, spatiotemporal semantic expression and visualization demand, and combines various application scenarios such as environmental construction. A comprehensive framework of agent-environment interaction is established using spatiotemporal grid partitioning. In the Earth research range of -12 km to 100 km, the CGCS2000 reference ellipsoid is chosen as the unified basis for spherical grid division and Earth height stratification. The spherical and radial divisions are independent of each other, better ensuring the structural spatial features and diversity of data attributes. The modeling process mainly includes the following three parts.

3.1 Geospatial and Temporal Ontology (GeoSOT) spherical latitude and longitude partitioning

The GeoSOT model is a global partitioning grid model proposed by Chinese scholars Cheng Chengqi et al. in 2016[6]. Its core idea is to expand the zero-level latitude and longitude of the earth to cover the globe, taking the intersection of the zero meridian and the equator as the grid center point, and forming a set of integer grids covering the world. The grid system is created through hierarchical quadtree partitioning with multiple levels of nesting and no overlap. By recording the coordinates of the nearest vertex from the center point distance, each grid unit is mapped to a unique character and number combination code, providing a unique spatial index for the global sphere that has good aggregation and correlation with existing spatial information grids. The resulting 32-level grid partitioning system can cover the current battlefield environment data results and provide good support for multi-resolution expression of environmental data. Based on the GeoSOT spatial coding, the "General Technical Requirements for Information Data Interconnection of Military and Civilian Common Resources" (GB/T 38991-2020) has been formally implemented in February 2021 to achieve effective connection with current military and civilian common resource data. Therefore, this article continues to use GeoSOT's partitioning method for the sphere to achieve a reasonable expression of environmental information.

3.2 Radial partitioning

Height/depth stratification of the spatial range between -12 km and 100 km. On the basis of standard stratification, considering the application requirements of the differences in various spatial environmental physical factors, a new stratification standard is established within the research range (Figure 2).

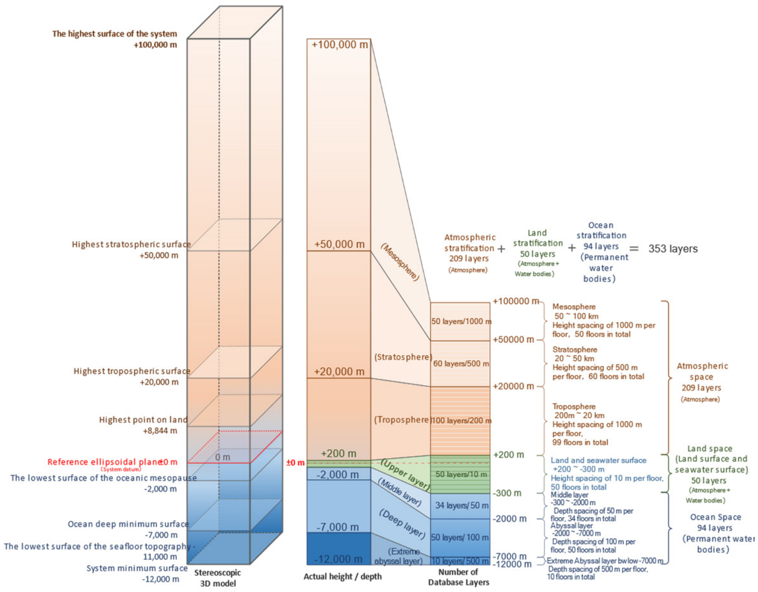

Figure.2 Results of Grid Volume Division.

3.3 Grid body encoding

To meet different application needs and achieve more efficient expression of each grid body, spherical and height encoding need to be independent. Figure 2 shows that the spherical encoding uses the GeoSOT encoding rule based on the Z-order encoding of the sphere, which to some extent ensures that adjacent storage of spatially adjacent grid units. For the recording of height/depth positions, the upper surface height values of the spatial grid above the reference surface are uniformly recorded, and the lower surface depth values of the spatial grid below the reference surface are uniformly recorded. To avoid negative numbers, the encoding is composed of the actual recorded height/depth value plus 12,000. Therefore, each spatial code for each grid body consists of two parts, representing the height position and plane position, such as G00131032_120300.

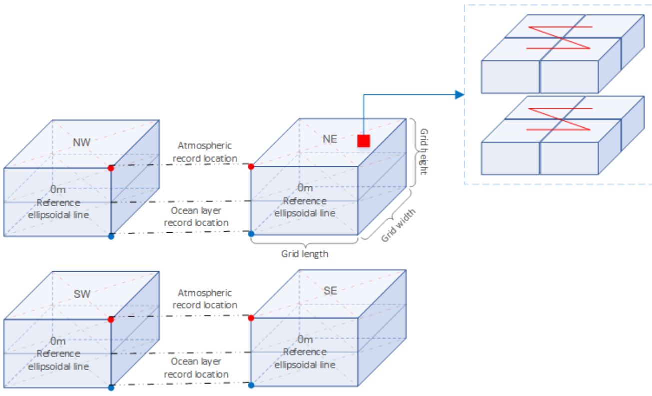

Figure.3 Schematic Diagram of Grid Volume Object Recording.

4 DESIGN AND IMPLEMENTATION OF ENVIRONMENTAL DATA MODEL

4.1 Model organization framework

Agents can automatically perceive and display environmental features at any time and space position. They can acquire spatial latitude, longitude information and time information through sensors, storing the collected environmental features as records. When performing analysis and visualization, it is necessary to consider the specific task requirements, scene expression requirements, and calculate the current amount of data collected while intelligently selecting a reasonable grid level. Furthermore, it is necessary to establish additional self-expression rules and association constraints based on environmental data grid entities to better serve environmental modeling and model prediction.

Therefore, this paper extends the object-oriented concept and treats grid entities as definable and describable objects, which inherently possess spatial, temporal, semantic, and relational attributes. As a whole, these grid entities exhibit hierarchical nesting, dynamic change, and holistic characteristics. Hierarchical nesting refers to the division of spherical partition grid levels, where higher levels yield more grid objects, each of which expresses a smaller spatial range. Large grid objects contain and inherit from smaller grid objects, and small grid objects interact with each other, which allows, for a single environmental feature expression, large grid objects to directly reference the entire content of small grid objects, while also existing across different grid levels. The dynamic change of grid entities mainly relies on the discrete ability of time attributes, dividing the internal environmental features of grid entities according to specific time intervals to realize continuous dynamic changes in the time dimension, supporting real-time updates of the environment. Holism is the natural manifestation of an object-oriented concept, requiring the explicit construction of the mutual relationships and causal links among the elements inside grid entities, providing organization and retrieval of internal environmental data, and the exploration and discovery of environmental evolution rules.

For environmental applications, environmental elements can take the form of objects, events, and phenomena, including geology, terrain, atmosphere, hydrology, man-made objects (buildings, weapons, equipment, etc.), and biology (vegetation, etc.). Objects, events, and phenomena are encapsulated within the grid cell object, which is given spatial and temporal characteristics and connections, as well as inherent attribute and semantic characteristics, facilitating retrieval and expression of individual elements.

Based on the above analysis, the conceptual model of the grid-based volumetric data model proposed in this paper is shown in equation (1):

$$SG_{S-T} = \{< E(obj, eve, phe), A, R, S >| f(SG_{S-T})\} \quad (1)$$

In the equation, the spatiotemporal encoding of the grid cell object is represented by E, which includes environmental elements (a) expressed in the form of objects, events, and phenomena, and independently possessing attribute, semantic, and relational characteristics, usually in vector space. B represents the attribute description of the grid cell, used to describe the basic spatiotemporal dimensions, hierarchy, and range of the grid cell. The relationships between multiple grid objects are established through spatial (adjacency and hierarchical inclusion) and feature association relationships. C is the semantic interpretation of the grid cell, used to reveal the geographic semantics and expression of the grid cell object in the battlefield environment. D is the query and retrieval result based on the encoding of the grid cell object.

The organizational framework of the model is shown in Figure 4.

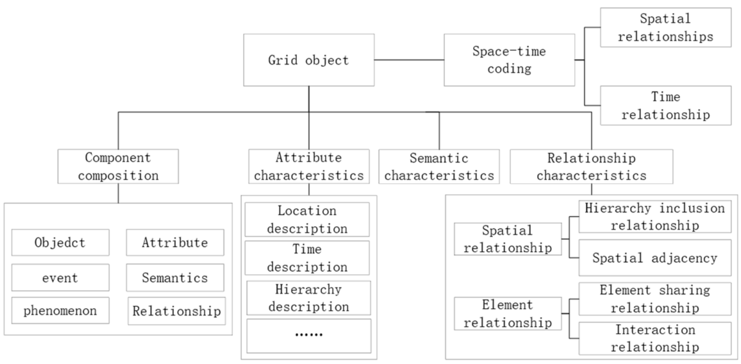

Figure.4 Organization Framework of Model.

4.2 Conceptual model design of model

Agents establish connections among internal environments within grid entities through spatiotemporal coding, constructing the inherent relationships among grid entities. Agents express the environmental system through grid entities in the spatiotemporal domain, considering both internal features and internal-external associations, facilitating the unified storage of various data types and efficient analysis and calculation. This approach is of significant value to the research of feature change mechanisms and the construction of environmental scenes.

As shown in Figure 5, this data model is based on the grid entity framework, takes grid entities as research objects, inherits methods of spatiotemporal domain encoding, and associates the internal environmental components, attribute descriptions, semantic interpretations, and external connections of grid entities through unique encoding. Additionally, the internal environmental components are also correlated based on the element ID's type, attribute, semantic, and relationship system. By implementing a data parsing interface, the model meets the storage and expression requirements of multi-source, heterogeneous environmental data. Simultaneously, by attributing grid entities' properties, semantics, and relationships from a traceability perspective, the model provides a comprehensive support for the construction of environmental scenes.

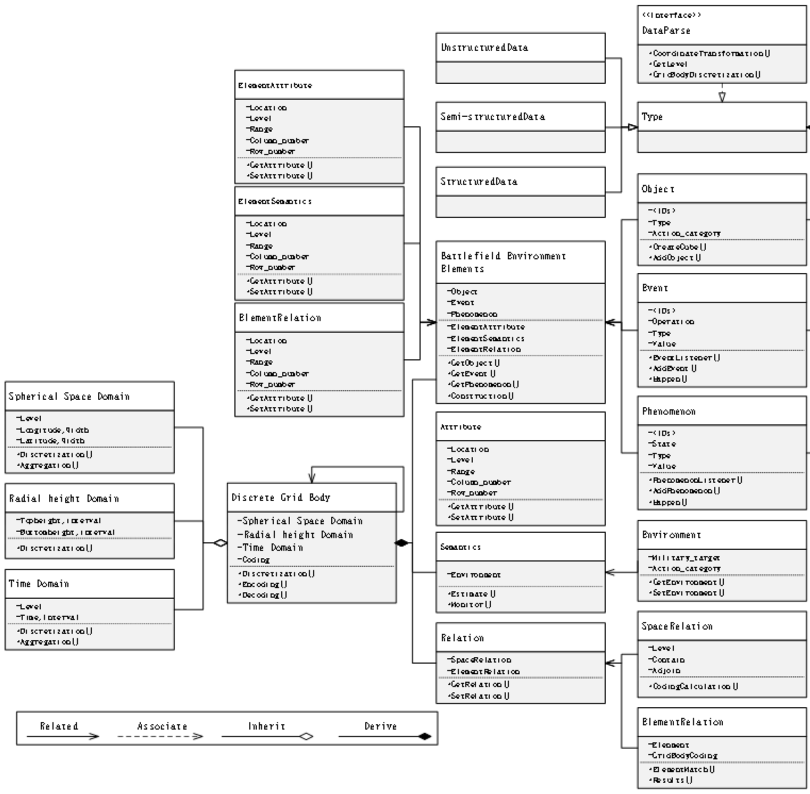

Figure. 5 UML Class Diagram of Model.

5 VIRTUAL BATTLEFIELD ENVIRONMENT SIMULATION EXPERIMENT

5.1 Experimental design and implementation

The contemporary battlefield environment is a crucial part of information construction, and complete and accurate environmental feature information is of vital significance in building comprehensive and precise battlefield environments. Utilizing agents to perceive environmental features, transmit structured perception and analysis results, visualize battlefield environments, and assist in situation analysis is an essential application direction for agent environment modeling. Loading agents on various equipment, leveraging sensor technology to perceive environmental data in the spatial environment, and establishing related mathematical models allows continuous monitoring of the space and time domain to compare changes. Agents independently discover and record the internal evolution of the current environment, storing, expressing, and analyzing predictions in the form of grid entities. Taking Anti-Submarine Warfare (ASW) task environment as an example, this paper simulates the role of agents in environmental modeling.

Anti-Submarine Warfare (ASW) encompasses a range of military actions and tasks that involve using diverse means and equipment to search for, detect, expel, attack, and destroy submarines underwater. It represents one of the most complex composite environmental battlefields in modern warfare, requiring efficient spatiotemporal data models to provide accurate information support.

(1) Combat Objectives and Tasks.

In a given sea area, there are hostile military examples between opposing red and blue forces. The red fleet aims to protect escorted ships from being approached by blue nuclear submarines and ensure their smooth passage through the submarine activity area to reach the destination port G as directed. The situation of both sides is shown in Table 1.

Table.1 Summary of the Situation of Both Sides in Combat.

	Equipment	Remark
Red side situation	Frigates (main ships, supply ships)	2 ships, carrying agent
	Corvettes	4 ships, carrying agent
	Anti-submarine helicopter (carried by a frigate)	carrying agent
	Anti-submarine patrol aircraft	With active sonar buoys and passive sonar buoys
Blue side situation	Attack nuclear submarines	Carry variable depth towing, bow multi-class active sonar

(2) Combat Environment Elements and Task Analysis.

The ASW process typically involves deploying the anti-submarine baseline by our anti-submarine patrol aircraft in a designated area in front of the escorted ships. If a submarine crosses the baseline or produces acoustic convergence effects due to high-speed sailing, the anti-submarine patrol aircraft detects the enemy target and coordinates with the anti-submarine helicopter to attack it while adjusting the heading and speed of the escorted ships at any time to ensure the completion of the escort mission. Therefore, when conducting experimental simulations, multiple types of battlefield environmental information such as ocean depth, hydrology, atmosphere, and electromagnetic waves in the sea area should be obtained to assist task decision-making and unified organization. Figure 6 provides a detailed profile of the anti-submarine experimental task.

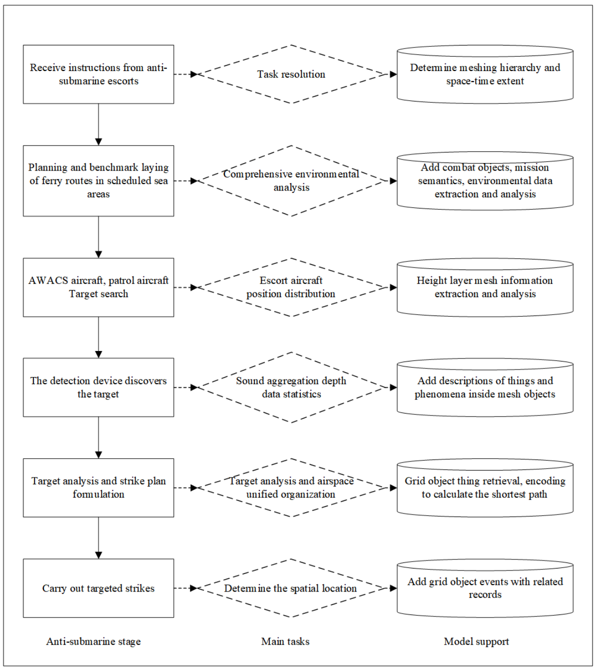

Figure.6 Analysis of Anti-submarine Warfare and Mission Profile.

(3) Example of Data Model

In order to clearly describe the role of agents in perceiving environmental features, the data model is instantiated for the ASW mission, and grid entity records are demonstrated in Table 2.

Table.2 Records of Anti-submarine Warfare Experimental Grid Division Data Model.

Grid object description	Content instance
Space-time location	Time coding, height coding, GeoSOT coding
Objects and descriptions	Frigates, frigates, anti-submarine patrol aircraft, models of attacking nuclear submarines, attack capabilities, maximum speed, radius of rotation, mutual space and semantic relations, etc
Events and descriptions	Target discovery, helicopter dispatch, adjustment of the itinerary of the frigate, attack target, target damage, target return, etc
Phenomena and descriptions	Clouds obscured, waves, etc
Grid properties	Spatial position, grid hierarchy, grid edge length, etc
Relationships	object, event, phenomenon sharing, unified path planning, grid hierarchy nesting, etc
Semantics	Voyage trajectory, target location, mission record, etc

5.2 Environmental simulation process and result analysis

The simulation experimental results are shown in Figure 7.

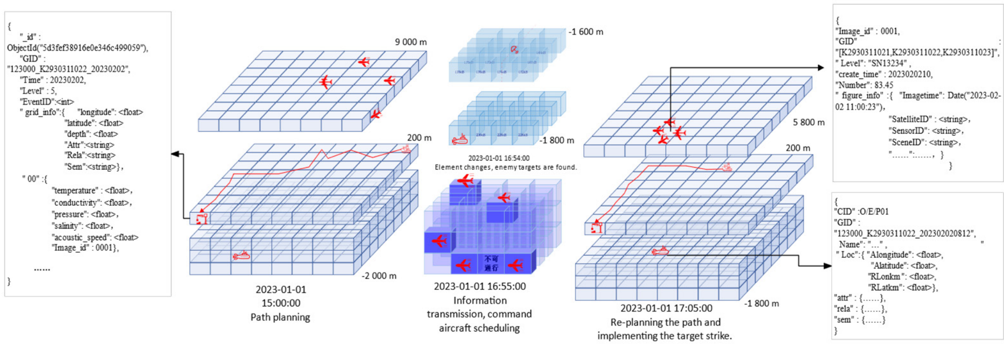

Figure.7 Model Application in Anti-submarine Warfare Experiment.

Firstly, intelligent agents need to use historical data to represent various inherent entities within a certain spatial range, and utilize sensor technology to sense meteorological data such as temperature, humidity, and atmospheric pressure in the current environment, establish meteorological data models, and plan paths driven by tasks and objectives. Secondly, when an environmental element detected by the intelligent agent experiences a change that exceeds the threshold, it will cause an event expression within a certain range of the region. Factors that cause the change will be analyzed and predicted by element analysis and information transmission, assisting the command center in making decisions such as airspace scheduling and implementing targeted strikes. Finally, the intelligent agent will receive unified dispatch tasks, and combine the danger zone identification, event identification, and marine meteorological data detection results to replan the paths, achieving the purpose of anti-submarine warfare.

If based on traditional vector calculation methods and model expressions, route planning would be very complex, and the full use of intelligent agent data cannot be realized. This would be detrimental to the completeness and efficiency of environmental reconstruction, thus affecting the efficiency and accuracy of the intelligent agent's task execution. As shown in the figure, the intelligent agent will logically divide the sea and airspace within the task area range and obtain environmental elements at different spatiotemporal positions through self-movement, realizing data recording and expression in the form of grid bodies. Layered heights help patrol aircraft to deploy three-dimensionally and record the depths of acoustic aggregation phenomena accurately. The measurability and hierarchical nesting characteristics of grids help precisely target combat objectives and make combat planning decisions. Finally, related events or phenomena are recorded in grid objects, synchronously recording spatiotemporal positions, and improving the traceability and analysis capabilities of subsequent anti-submarine operations.

6 CONCLUSIONS

This paper, in view of the extensive applications of contemporary intelligent agents, conducts a comprehensive analysis of the abilities of intelligent agents in environmental element sensing, storage, expression, analysis, and visualization. This methodology has significant application value in the construction of environmental element models. The spatial grid partitioning framework is utilized to achieve unified recording of the spatiotemporal characteristics of environmental elements. The environmental element expression model oriented towards grid body objects is proposed, taking all things, events, and phenomena within the grid body as the inherent attributes of the grid body objects. This further enhances the efficiency of interaction between intelligent agents and the environment, satisfies the unified organization of multi-temporal and multi-format data sensed by intelligent agents, and is conducive to the establishment of various learning models and the exploration of environmental mechanisms. Based on this, the application of intelligent agent environmental modeling in the military field is simulated and explained. JSON statements are used to express and transmit sensed data and analysis results in a structured manner, achieving task scheduling and demonstrating the role of intelligent agents throughout the entire combat environment process. The development of more effective sensing technologies to achieve multi-intelligent agent cooperative sensing and information transmission, especially the real-time expression and visualization analysis capabilities of elements, will become an important driving force for the application of intelligent agents in more fields.

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