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# Investigation of MAS structure and intelligent$^+$ information processing mechanism of hypersonic target detection and recognition system

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**Abstract:** The hypersonic target detection and recognition system is studied, on the basis of overall planning and design, a multi-agent system (MAS) structure and intelligent$^+$ information processing mechanism based on target detection and recognition are proposed, and the multi-agent operation process is analyzed and designed in detail. In the specific agents construction, the information fusion technology is introduced to defining the embedded agents and their interrelations in the system structure, and the intelligent processing ability of complex and uncertain problems is emphatically analyzed from the aspects of autonomy and collaboration. The aim is to optimize the information processing strategy of the hypersonic target detection and recognition system and improve the robustness and rapidity of the system.

**Keywords:** hypersonic target, detection recognition, intelligent information fusion, multi-agent system (MAS).

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## 1. Introduction

In recent years, a kind of "high, fast, hidden" target has been emerging in the world, which is a hypersonic vehicle in adjacent space. Hypersonic targets mainly include hypersonic aircraft and hypersonic missiles, among which hypersonic aircraft is mainly used for global surveillance and reconnaissance, while the hypersonic missile is mainly used to strike key targets around the world. Their flight altitudes are 20 km−100 km, flight speeds are over Mach 5, and radar scattering areas are less than 0.1 $m^2$ [1−3]. So far, the United States, Russia, India, Japan, Israelandothercountrieshaveinvestedagreatdealofhumanandfinancial resources to the research, and some of the results have been put into experiments, which show a gradually accelerating momentum.

In fact, long-range ballistic missiles and intercontinental ballistic missiles are also hypersonic weapons. According to Newton's classical mechanics, the two missiles would shoot out of the atmosphere at the first cosmic velocity, that is 7.9 km/s and is equivalent to Mach 23.6. Therefore, the average speed of the ballistic missile is over March 15 without any problem. The hypersonic vehicle has the characteristics of high flight height, high speed, and strong mobility. Because of the limitation of tactics and technology for a single detection platform, it is difficult to capture and track the target stably.

The rapid and accurate hypersonic target detection and recognition system is a very complex system. It is restricted by sensor technology, computer technology and information technology, and it is also restricted by the essential understanding and application of information fusion system to intelligent information processing [4]. Some research progresses have been made abroad, while in China, it is basically in the initial stage, and most of the research focuses on fusion methods and optimization criteria. The public studies combining multi-sensor information fusion with hypersonic target detection and recognition architecture have been rarely reported [5−7].

## 2. Structure of hypersonic target detection and recognition system based on multi-agent system (MAS)

### 2.1 MAS design philosophy

At present, the architecture of target detection and recognition system, only involve three ways: centralized, distributted and hybrid. The traditional thinking determines a structure, and chooses a program or method, which does not change with the change of the target state. Therefore, it reduces the efficiency and flexibility of the detection and recognition system, making it less adaptive and intel-

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ligent [8,9]. However, due to the deficiency of target priori information and the variability of environment in hypersonic target defense, it is impossible to determine an optimal recognition model in advance, and the fixed model will be difficult to adapt to the high-speed dynamic change of the target. The battle and defense process of hypersonic weapons is shown in Fig. 1.

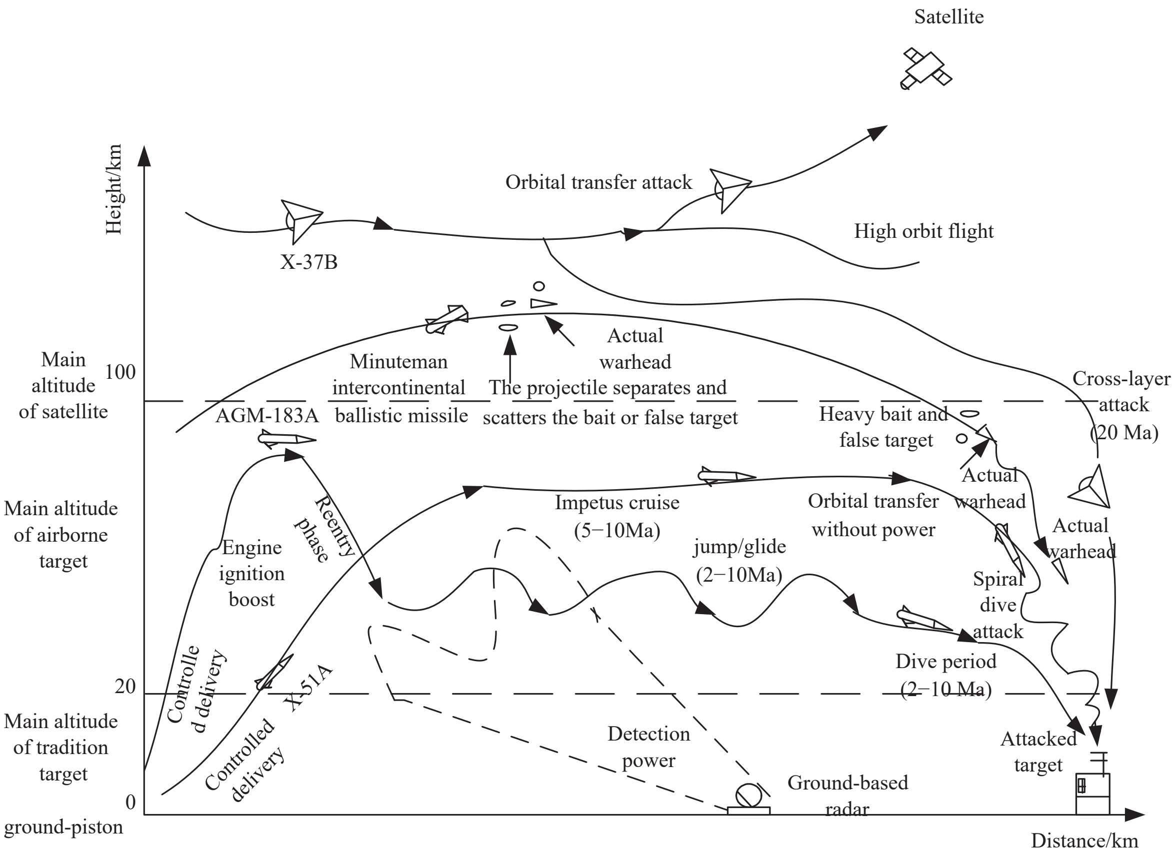



**Fig. 1 Schematic diagram of hypersonic weapons combat and defense process**

As a relatively new research direction in the field of artificial intelligence, the MAS technology has the characteristics of autonomy, distribution, coordination and hierarchy, and can represent heterogeneous sensors as agents. Therefore, the MAS technology has incomparable expression ability for complex systems and provides a unified model for various practical systems [10,11]. In the construction of multi-sensor information fusion system, compared with the general distributed system, it can better adapt to the dynamic and changeable tasks and targets, which is helpful to physical entity layout, as well as the intelligent processing of information fusion. It is considered as an important technology and framework for building complex distributed information processing systems.

Based on the analysis of the above hypersonic target detection and recognition system and the characteristics of MAS, this paper believes that using the MAS technology to design the architecture of hypersonic target detection and recognition system is a scientific choice. Therefore, the target detection and recognition system based on MAS is proposed in this paper, to improve the adaptability of the hypersonic target detection and recognition system for different sensor states and target types by the agent's autonomy, cooperation and other intelligent characteristics, and to flexibly utilize the multidimensional information processing mode of information fusion to improve the efficiency of target recognition.

### 2.2 MAS architecture

On the specific MAS structure, as shown in Fig. 2, the system is a distributed remote multi-agent target detection and recognition system. It is composed of three nodes of the detection subsystem agent, recognition agent and management decision agent, and is divided into three layers according to the degree of data abstraction and main functions. It uses the idea of role-based task decomposition. On the one hand, each role is built by different hard and soft components to accomplish different functions; on the other hand, each role component has corresponding communication interfaces, which can communicate and coordinate information according to different system task requirements, and jointly complete complex tasks, so as to achieve the overall optimal system performance [12]. Moreover, the structure model reflects the advantages of open design and modular system, which is conducive to system upgrade, and improves the system flexibility and scalability.

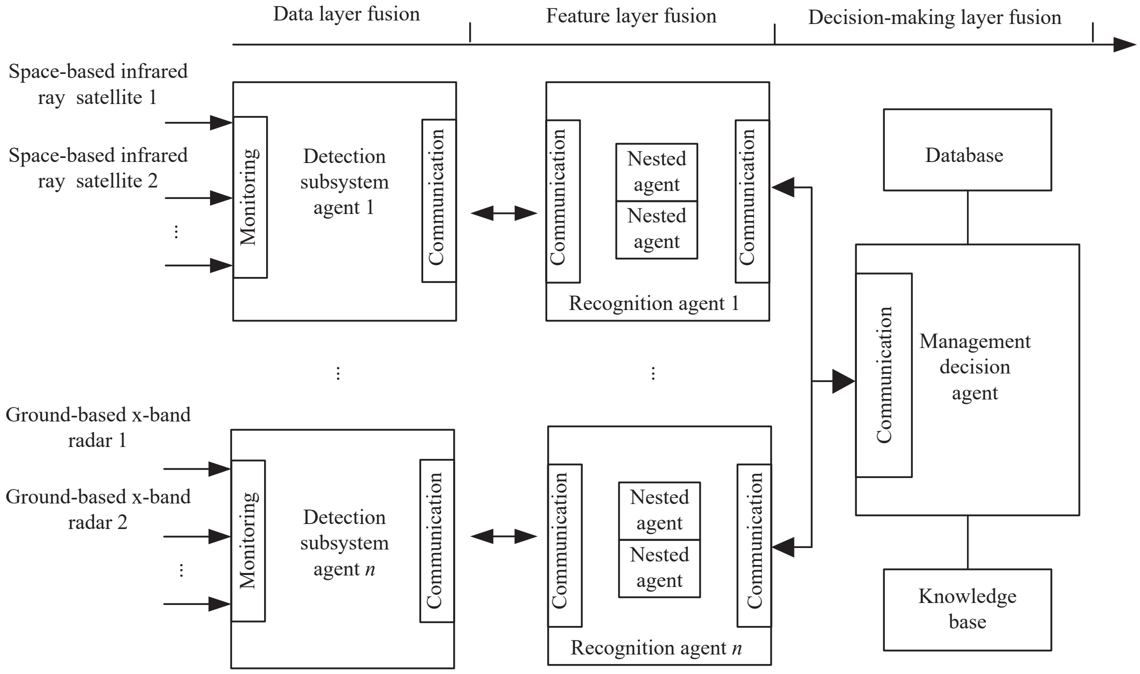



**Fig. 2 Architecture of hypersonic target detection and recognition system based on MAS**

In the process of task execution, the system firstly uses sensors in various detection subsystem agents to detect hypersonic targets. After the targets are found, the recognition agent makes fusion judgment according to the initial recognition results for each hypersonic target; the management decision agent makes decisions according to situation recognition, understands and decomposes the combat tasks, assigns the corresponding tasks to the recognition agent or the detection subsystem agent, and exerts its characteristic or changes its working mode to further recognize the key target. At the same time, it is considered whether other detection subsystem agent or recognition agent is needed for collaboration. In the process of executing combat tasks, each agent realizes the cooperation and communication with other agents through the communication interface.

### 2.3 Function and construction of agent

(i) The detection subsystem agent mainly collects, processes and stores the data from several similar sensors, unifies multi-sensor information into a common space-time reference system, and gives a unified, clear and reliable description of the battlefield environment. When the abnormal situation is found, the report will be submitted to the management decision agent in time, the target local characteristic data after the associated registration and fusion will be sent to the recognition agent, and the management and dynamic scheduling of sensor-level tasks will be accepted by the management decision agent. Since the research content in this paper is mainly in the recognition stage, no further discussion is made on the sensor measurement stage, and the initial recognition results are directly simulated by the sensor.

(ii) The recognition agent mainly carries out information fusion based on the local characteristics of targets detected by one or several similar sensors through various information fusion algorithms, and establishes the recognized target linked list to provide command and decision-making basis for the management decision agent. At the same time, the change of the target state and the urgency of attack are analyzed. Once a conclusion is reached, it is timely released to other agents. Its functional structure is shown in Fig. 3. Because there is no perfect algorithm to solve all kinds of problems, each method has its advantages and disadvantages. Therefore, by combining various methods and making full use of their respective advantages, when processing the fusion information, appropriate algorithms can be selected according to the uncertain factors in the repressentation form of the information of target characteristics and changes, so as to achieve better results. A number of fusion agents with different algorithms are embedded in the recognition agent. When identifying the target, the results are compared with other nested fusion agents through the messaging passing mode. When the results are consistent, the credibility or weight of the fusion agents is increased; when the recognition results are inconsistent, they are directly submitted to the decision agent for final fusion judgment.

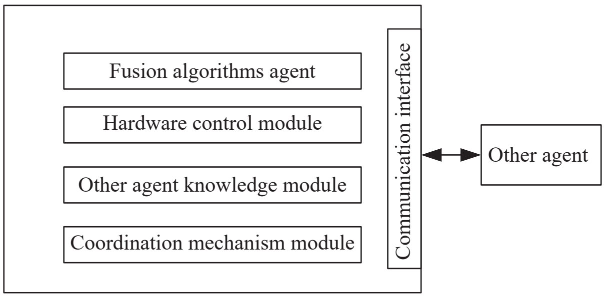



**Fig. 3 Structure diagram of the embedded recognition agent**

The remarkable feature of the recognition agent is that it can combine multiple target characteristics with information relevance, such as radiation intensity characteristic, temperature change rate characteristic, heat capacity difference characteristic, etc., all of which are the embodiment of target infrared characteristics, so they can constitute the target local comprehensive feature. Then it can maximize the role of information correlation, improve the information utilization, and reduce the characteristic dimensions and the overall calculation amount, and it is convenient to coordinate and manage similar sensors with similar characteristics.

(iii) The management decision agent mainly synchronizes the asynchronous information of each recognition agent to generate the consistent description of the targets. Considering the different characterizations of target group characteristics of each detection subsystem agent and the limited ability of a single recognition agent, it is necessarytominimizetheimpactofsingularresultsonfusionresults, and increase the fault tolerance of the system and the certainty of the results. The management decision agent can choose the reasonable fusion algorithm and complete the final goal discrimination through some decision rules, or make a quick response to the emergency according to the existing knowledge and scheme. At the same time, the target information stored in the database is compared with the sensor information, and the recognition process and result are stored in the knowledge base, or relevant experience and knowledge are called out from the knowledge base for auxiliary decision-making. It is responsible for the initiation, coordination and termination of the task, as well as the management of the sensors, and forms the task list of each decision and writes them into the blackboard model. In addition, the structures of the management decision agent and the recognition agent are roughly the same. The only difference is that there is more database and knowledge base, and no embedded agents.

### 2.4 Multi-agent coordination planning workflow

The cooperation among agents is mainly in the form of dynamic driving cooperation based on various characteristics changing in hypersonic target flight. Therefore, first of all, each sensor member shall implement the plan according to their own capabilities and the task distribution, cooperate with other sensor members as required, and solve the existing conflicts through negotiation after the formation the initial operational plan [13,14]. The decision-making body is responsible for centralized planning of the inconsistencies among sensors [15]. Therefore, this paper proposes a coordinated planning method of hypersonic target detection and recognition system based on MAS combining distribution and concentration. It comprehensively solves the system task decomposition and assignment from three aspects of function, structure and flow, and the main steps are as follows:

**Step 1** According to the task assignment of the management decision agent, the detection sub-system agent is responsible for early warning and monitoring of hypersonic target launch in its responsibility area.

**Step 2** When a certain detection subsystem agent discovers the suspicious hypersonic target emission, it will report the situation to the recognition agent and the management decision agent, and inform other similar sensors in the detection subsystem to cooperate in the detection.

**Step 3** The detection subsystem agent coordinates the internal sensors for data-layer information fusion and error correction, and obtains high-quality target information to improve the target recognition performance.

**Step 4** The recognition agent conducts fusion recognition according to the target information. Since the recognition agent grasps the information of sensor capability in the detection subsystem agent, the target characteristic information obtained by them will be given corresponding weight before fusion. Within the recognition agent, an embedded agent will send the target classification recognition results that it considers to be of greater reliability to other embedded agents in the form of message passing. After other embedded agents compare their own results with them, if the conclusions are consistent, the credibility of the recognition results will be increased, and the consistency results of the recognition agent will be sent to the management decision agent; if the results are inconsistent or uncertain, all the information will be directly sent to the management decision agent, which will coordinate the rest of the recognition agents for fusion identification.

**Step 5** On this basis, other recognition agents reduce the scope of target recognition with the elimination method to improve efficiency. On the other hand, if the recognition agent obtains satisfactory identification results at a certain fusion level, the management decision agent can directly make the final identification judgment and threat ranking. In the process of fusion recognition, the corresponding knowledge source (such as database and knowledge base) can be immediately started to deal with the uncertain results. Each recognition agent dynamically adjusts its weight according to the working state of the sensor, and the management decision-making agent adjusts the weight of the recognition agent according to the recognition results embedded in the recognition agent.

**Step 6** According to the target characteristics and operating conditions, the management decision-making agent selects and coordinates different detection subsystem agents and recognition agents in time to allocate and combine tasks according to the characteristics assessment and optimization combination knowledge, dynamically determines whether the system achieves the best fusion result, and controls the timing sequence of the system and the start-stop operation of task instructions.

**Step 7** When the target flies out of the responsibility area of the detection subsystem agent, the management decision-making agent will transfer the target according to the situation, and start the next detection subsystem agent. The task of the original detection subsystem agent is completed, then it exits the plan.

**Step 8** After the hypersonic target is recognized and intercepted, the detection subsystem agent and the recognition agent will evaluate the interception effect. If the hypersonic target is destroyed, the coordination planning will be finished.

# 3. Intelligent$^+$ information processing mechanism

## 3.1 Intelligence$^+$ information fusion hierarchical model

In the case of hypersonic target detection and recognition system, information fusion should be a multi-level, multi-aspect and multi-stage process for multi-source information, constantly generating new meaningful information, so as to improve the accuracy and efficiency of target recognition and make better decisions. The basic strategy of the fusion hierarchy division is to first fuse the information at the same lower level, obtain the fusion information at a higher level, and then enter the next information fusion level; at the same time, the high level information can also intervene the low level fusion through the decision system when needed. From the data layer to the decision-making layer, each layer has independent fusion results, which can be used for reference and comparison of the decision-making system. The information and results of each fusion node can also interact with other nodes, as shown in Fig. 4.

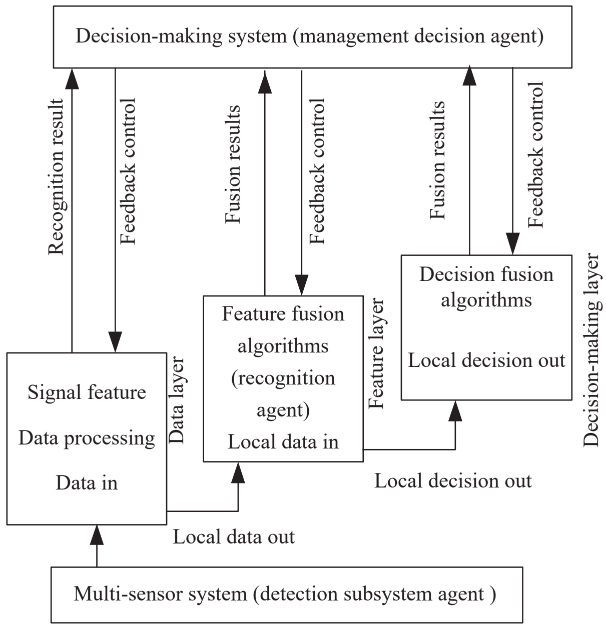



**Fig. 4 Hierarchical model of information fusion for hypersonic target detection and recognition system**

Such advantages are as follows: on the one hand, if the fusion result is satisfactory at a certain level, it can directly enter into the decision-making system for corresponding decision-making generation and feedback control, which can save time; on the other hand, the fusion results at different layers can verify each other, ensure the reliability of the results, and maximize the use of effective reources. In case of conflicts, further tests are required.

## 3.2 Intelligent$^+$ information processing

Based on the above, this section further proposes a basic framework for intelligent$^+$ information processing, which is shown in Fig. 5. The basic framework analyzes the input state, corrects the sensor states and extracted features, and then selects the dynamic feature according to these two factors combined with the prior knowledge of target feature evaluation. Accordingly, the fusion algorithm and decision rules will be changed and adjusted according to the situation [16]. Corresponding to the MAS coordination planning, the cognitive closed-loop mechanism with good robustness and adaptive ability is constituted, which comprises the following steps.

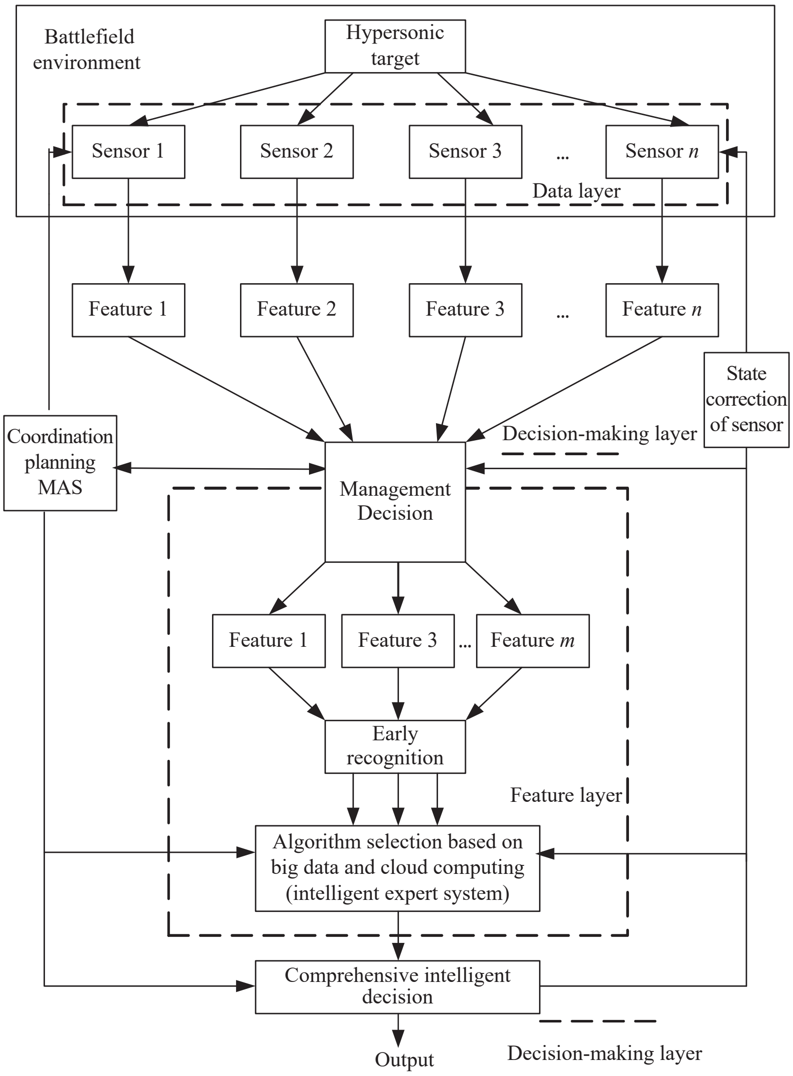



**Fig. 5 Basic framework of intelligent+ information processing**

**Step 1** Due to the natural environment, electronic interference, sensor performance, target state and other factors, may lead to the corresponding target feature extraction and recognition "desensitization". The management decision agent is used to evaluate the characteristics, and then the relative index weight coefficient is assigned to the component factors such as the sensor state and target characteristic [17] (it is the previous research result from the first author of this paper).

**Step 2** According to the evaluation results, the sensor state is modified and the target characteristics are selected as the input of the management decision. Combined with the prior knowledge of features selection and combination, the candidate features can be optimized combination at the right time (the corresponding sensors coordinate with each other) [17].

**Step 3** Through the features combination, the expert system can select the corresponding fusion algorithm according to the obtained target information. The selection of fusion algorithms depends on the reasoning property, specific application and valid sensor data for the fusion system (see below).

**Step 4** The initial recognition of the sensor is the reliability value of each target type, and then the reliability value is used as the input of the two decision-layer fusion algorithms for fusion calculation.

**Step 5** Finally, the rule-based target decision threshold and the comprehensive decision are used to make decisions (the second threshold). If it is not reached, return to Step 3.

## 3.3 About mathematical description

### 3.3.1 Fusion algorithm selection

When selecting fusion algorithm, in addition to the target running state, the balance relationship between features and limitations of each method should be considered.

Generally, the recognition algorithms accommodated in the system should form a complementary relationship.

Therefore, when the intelligent expert system selects the best fusion algorithm and decision judgment, the rule of knowledge repressentation method is adopted as the processing strategy, and its form is "If…Then...". Here, we take the Dempster-Shafer (DS) fusion algorithm and the fuzzy fusion algorithm in [18,19] as examples.

(i) If (there is a serious conflict among the multi-sensor judgment of the targets)

Then (the DS fusion algorithm is used)

(ii) If (the sensor information and target features are fuzzy and uncertain)

Then (the fuzzy fusion algorithm is used)

(iii) If (the decision result of a certain method still cannot determine the target type)

Then (enable another method)

(iv) If (the conclusions of the two methods are consistent)

Then (integrate the consistent results into a decision)

(v) If (the two methods have different conclusions)

Then (all information is sent directly to the integrated decision section, which coordinates the decision)

3.3.2 Target type determination rule

In hypersonic target recognition, the system is most concerned about the reliability judgment of various target types in the target group. Then the recognition credibility frame can be set as {hypersonic aircraft, hypersonic cruise missile, hypersonic glide missile, debris}= $\{f_1, f_2, f_3, f_4\}$, which corresponds to four possible decisions:

(i) $V_{i1}(T)$ determines the reliability of target $i$ for hypersonic aircraft at the time node $T$ by the fusion algorithm agent $e_k$;

(ii) $V_{i2}(T)$ determines the reliability of target $i$ for the hypersonic cruise missile at the time node $T$ by the fusion algorithm agent $e_k$;

(iii) $V_{i3}(T)$ determines the reliability of target $i$ for the hypersonic glide missile at the time node $T$ by the fusion algorithm agent $e_k$;

(iv) $V_{i4}(T)$ determines the reliability of target $i$ for debris at the time node $T$ by the fusion algorithm agent $e_k$.

$$V_{i1}^k(T)+V_{i2}^k(T)+V_{i3}^k(T)+V_{i4}^k(T)=1 \tag{1}$$

Until the time node $T$, the fusion algorithm agent $e_k$ judges that the target is the possibility of each type in the recognition credibility frame.

$$G_i^k(T)=F[V_{i1}^k(T),V_{i2}^k(T),V_{i3}^k(T),V_{i4}^k(T)] \tag{2}$$

where $F$ is the fusion recognition method.

According to the actual situation, in order to make the judgment of target type accurately, the target judgment principle is set as follows.

(i) The determined target type should have the corresponding maximum reliability function value.

(ii) The difference between the reliability function value of the determined target type and that of other possible types is larger than a certain threshold. Generally speaking, the higher the threshold value is, the higher the accuracy of target recognition will be. However, if the threshold value is too large, the reliability value of the determining target type is often unable to meet the requirements and the result cannot be obtained. Therefore, according to the characteristics of target recognition, this threshold can be set by

$$V_{\max}-V_{\sec}>\frac{1}{n} \tag{3}$$

where $V_{\max}$ represents the maximum confidence value of the intended target type, $V_{\sec}$ represents the second highest confidence value in the intended target type, and $n$ is the number of target types to be judged (here $n$=4). In general, the threshold is a value greater than $1/n$, where 0.35 is the first threshold. Since the main method of hypersonic target recognition is to determine the shape type of the target through fusion of various sensors, when $V_{\max}-V_{\sec}\geqslant 0.35$, it can be considered that at this point, the target can be definitely determined as the target type.

3.3.3 Comprehensive decision

Assuming that fuzzy fusion algorithm agent and the DS fusion algorithm agent are used, the ability level of each nested fusion recognition agent is $r^1=r^2=0.5$, and the system's judgment on the four decisions is $U_{im}$, indicating the support degree of the system to the decision.

$$G_i(T)=RV=[r^1,r^2]\begin{bmatrix} V_{i1}^1(T),V_{i2}^1(T),V_{i3}^1(T),V_{i4}^1(T) \\ V_{i1}^2(T),V_{i2}^2(T),V_{i3}^2(T),V_{i4}^2(T) \end{bmatrix}= [U_{i1}(T),U_{i2}(T),U_{i3}(T),U_{i4}(T)] \tag{4}$$

If two nested fusion recognition agents fail to agree according to the decision rule on the judgment result of a certain target type, it can be temporarily defined as uncertainty, which means that the target recognition cannot make a positive judgment (meet the threshold) in an extreme case. The difference of the final reliability function value satisfies the second threshold of 0.25 after the system comprehensive decision (using feature evaluation and recognition agent characteristics), that is $U_{\max}-U_{\sec}\geqslant 0.25$. It indicates that the judgment difference is reduced between the two fusion recognition agents on the target type, so the conclusion can be made according to the target type of the maximum reliability function value.

## 4. Results and analysis

The overall framework of the scheme is described above, and the following part will focus on the effect demonstration of multi-sensor fusion judgment under the scheme. When a hypersonic target is running at a certain stage, the recognition system mainly modulates the target signal in reverse to deduce some physical properties of the target, such as the shape, structure, material, mass distribution and motion state. The detection and recognition system uses four technical approaches to measure and extract the temperature change rate, thermal imaging characteristic, one-dimensional range image characteristic and plasma sheath radar cross section (RCS) characteristic for target recognition, which mainly reflect the shape structure of the target, and then extrapolate the target type. The recognition framework is {hypersonic aircraft (target 1), hypersonic cruise missile (target 2), hypersonic glide missile (target 3), debris (target 4)}. The fusion recognition methods involve the fuzzy fusion algorithm and the DS fusion algorithm. The recognition process is divided into three stages, with three samples in each stage and a total of nine recognition nodes.

Through the feature evaluation method in [17], the system adopts different features (sensors) combination to form a dynamic task alliance at different recognition stages, and agents within the alliance cooperate and compete to jointly complete the recognition task. For the sake of simplicity, it is said that the use of a certain sensor measuring the feature of a certain target is a technical approach, as shown in Table 1.

**Table 1 Feature combination of system fusion recognition stage**

| Characteristic | Phase1 | Phase2 | Phase3 |
|---|---|---|---|
| Technology 1 | 1 | 0 | 1 |
| Technology 2 | 1 | 1 | 1 |
| Technology 3 | 1 | 1 | 0 |
| Technology 4 | 0 | 0 | 1 |

In Table 1, 1 indicates that the technical approach is involved in recognition, while 0 indicates that it is not.

Technology 1 is the temperature change rate, technology 2 is the thermal imaging characteristic, technology 3 is the one-dimensional range image characteristic, and technology 4 is the plasma sheath RCS characteristic.

In different recognition stages, each technical approach judges that each target belongs to the corresponding type with different degrees of credibility. It is based on target characteristic analysis and simulation environment setting, and then carries out the comparison among samples to obtain the credibility. At the same time, the credibility of the other three judgment decisions will be determined accordingly, as shown in Table 2, where "−" indicates that the technical approach is not involved in the recognition at this stage.

**Table 2 Target recognition result when $\sigma(T)$=0.30 and $T$=7**

| Target | Recognition method | Belief function $v_i$ | | | | Recognition result |
|---|---|---|---|---|---|---|
| | | $f_1$ | $f_2$ | $f_3$ | $f_4$ | |
| Target 1 | Technology 1 | 0.421 | 0.325 | 0.154 | 0.100 | Uncertainty |
| | Technology 2 | 0.404 | 0.334 | 0.132 | 0.130 | Uncertainty |
| | Technology 3 | − | − | − | − | − |
| | Technology 4 | 0.444 | 0.204 | 0.312 | 0.140 | Uncertainty |
| | Fuzzy fusion agent | 0.640 | 0.150 | 0.106 | 0.104 | $f_1$ |
| | DS fusion agent | 0.598 | 0.112 | 0.180 | 0.110 | $f_1$ |
| Target 2 | Technology 1 | 0.215 | 0.356 | 0.289 | 0.140 | Uncertainty |
| | Technology 2 | 0.231 | 0.424 | 0.245 | 0.100 | Uncertainty |
| | Technology 3 | − | − | − | − | − |
| | Technology 4 | 0.288 | 0.435 | 0.146 | 0.131 | Uncertainty |
| | Fuzzy fusion agent | 0.270 | 0.418 | 0.165 | 0.147 | Uncertainty |
| | DS fusion agent | 0.208 | 0.566 | 0.123 | 0.103 | $f_2$ |
| Target 3 | Technology 1 | 0.443 | 0.121 | 0.136 | 0.300 | Uncertainty |
| | Technology 2 | 0.278 | 0.426 | 0.191 | 0.105 | Uncertainty |
| | Technology 3 | − | − | − | − | − |
| | Technology 4 | 0.291 | 0.424 | 0.181 | 0.104 | Uncertainty |
| | Fuzzy fusion agent | 0.112 | 0.213 | 0.565 | 0.110 | $f_3$ |
| | DS fusion agent t | 0.156 | 0.201 | 0.559 | 0.084 | $f_3$ |
| Target 4 | Technology 1 | 0.154 | 0.107 | 0.061 | 0.678 | $f_4$ |
| | Technology 2 | 0.121 | 0.120 | 0.172 | 0.587 | $f_4$ |
| | Technology 3 | − | − | − | − | − |
| | Technology 4 | 0.134 | 0.014 | 0.179 | 0.673 | $f_4$ |
| | Fuzzy fusion agent | 0.176 | 0.038 | 0.151 | 0.635 | $f_4$ |
| | DS fusion agent | 0.160 | 0.101 | 0.102 | 0.637 | $f_4$ |

In different recognition stages, no matter the environment or the electronic interference will increase the deviation of target recognition by a single sensor (technical approach). In this paper, the influences of the above uncertainties on each technical approach are simulated, such as increasing the Gaussian noise of the system, and simulating the environment and electronic interference for the system. As a result, the working state of the sensor decreases, and the target judgment tends to be fuzzy and unstable.

In this case, if the decision is made in strict accordance with the judgment rules, it will require a longer time cycle, or require more target characteristics (information resources) for fusion judgment, but they are unfavorable to the hypersonic target detection and recognition system for efficiency and stability. The following node is selected in $\sigma(T)$=0.30 (Gaussian noise of the system) and $T$=7, and the recognition results of each technology approach and two recognition agents are compared. The results are shown in Table 2.

As can be seen from Table 2, if the decision rules are strictly followed, except for target 4 (common fragment), which can be identified in a single technical approach, the rest of the targets are not very clear in terms of type, and basically cannot meet the first judgment threshold. The experimental results also show that the fusion reliability of target 3 belonging to the hypersonic cruise missile is relatively high, which is mainly caused by the large recognition deviation for target 3 from the technical approaches 2 and 4. Due to the fusion and inheritance of the two fusion algorithms, the overall situation of the recognition agents are better than single recognition approaches, which reduces the uncertainty, but it is not optimistic. For target 2, the fuzzy fusion agent cannot meet the first judgment threshold and cannot reach complete consensus. In this case, the system needs to make a comprehensive decision in order to obtain further recognition results.

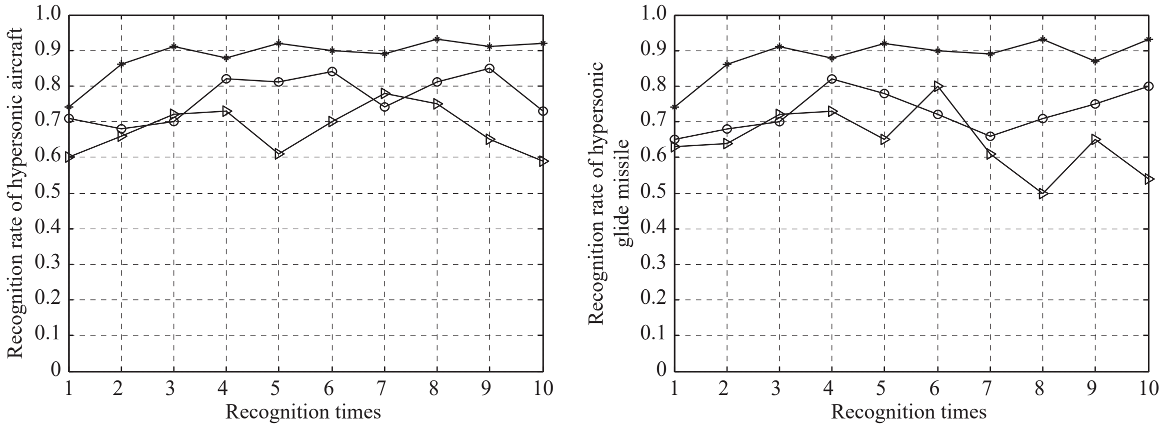
Although the corresponding conclusions can be drawn for other targets according to the first judgment threshold, the actual target type reliability function value of each fusion agent is still relatively small. When the judgment threshold is higher, the real target type cannot be recognized. Moreover, in some cases, their results are inconsistent, such as the judgment on target 2. At this time, all relevant data of the two agents can be sent to the management decision agent, which will make different processings according to different situations.

For example, the result of the fuzzy fusion agent is still uncertain, and the DS fusion agent can determine the target type, and the difference in the reliability function value of the corresponding target type satisfies the second threshold ($U_2-U_1$= 0.316>0.25) after the comprehensive decision, then the DS fusion agent result can be selected as the recognition conclusion (here it is the competition between two nested recognition agents). In addition, when the results of the three technical approaches are consistent, such as the judgment of target 4, the results can be directly transmitted to the management decision agent to make a quick conclusion, and eliminate the threat without further fusion, which can save time and resources. However, if the two identification results are uncertain or even contradictory, they are suspicious targets. The management decision agent needs to issue cooperative recognition instructions to other agents and provide relevant original data. Finally, by means of multi-detection agent and multi-recognition agent dynamic cooperative recognition, all the recognition results are integrated to make the final conclusion

Thus, the fuzzy fusion agent and the DS fusion agent supplement each other to form the recognition agent, as well as the competition and cooperation among the detection subsystems and among the recognition agents, which can obtain the recognition results more reliably and quickly.

Four kinds of target feature data are collected by four sensors, 50 samples in each data. Under this condition, the DS fusion agent, the fuzzy fusion agent and the intelligent$^+$ information processing model are separately used to compare the effectiveness of target recognition. The part recognition rates are shown in Fig. 6.

The experimental results show that the reliability of the single recognition technology fails to meet the requirements with the increase of the recognition deviation, and the performances of the two information fusion recognition methods decline and fluctuate greatly. This is mainly because the two fusion algorithms can only be fused according to a fixed program, but cannot conduct further intelligent reasoning and coordination fusion in the face of some special cases. The intelligent$^+$ information processing model proposed in this paper has a higher recognition accuracy than the two fusion algorithms (recognition agents), which fully reflects its ability to optimize and integrate system resources on the basis of the two algorithms, as well as its flexibility and intelligence under the dynamic and changeable complex conditions. After such treatment, the target recognition rates are improved and the recognition results are stable.




(a) $\sigma(T)$=0.30, recognition rate of three methods for target 1 (b) $\sigma(T)$=0.30, recognition rate of three methods for target 3

—▷—: DS method; —○—: Fuzzy fusion method; —✦—: Intelligent⁺ information processing model.

**Fig. 6 Recognition rates of three methods**

## 5. Conclusions

Aiming at the problem of hypersonic target detection and recognition, this paper proposes the MAS structure based on the combination of distribution and concentration, and mainly designs the information fusion intelligence$^+$ processing mechanism. The steps of coordinated planning and multiple intelligent information processing and application are expounded, and the effect is demonstrated. This scheme changes the solidified state of the information processing structure in the previous target detection and recognition system, which does not change with the sensor and the target state. It can enhance the adaptability and cooperation of information fusion and make target detection and recognition more intelligent.

The innovation of this scheme is mainly embodied in the following aspects of intelligence$^+$:

(i) Multi-intelligence. It is embodied in the multi-agent cooperation and competition based on the evaluation and selection of target characteristics, and the overall information fusion presents multi-level intelligent optimization.

(ii) Advanced intelligence. It is embodied in the cognitive closed loop of the information processing model and can self-adjust the system detection and recognition strategy according to the target and sensor states.

In the future, the scheme will be further studied on effective integration and performance evaluation to make it practical.

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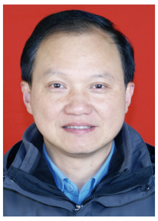

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