Research on Capability Catalog Generation of UAV Intelligent System Based on DoDAF

Yuexing Wang[1], Xiaoxu Dong[2], Jiazhi Yan[1], and Miao Wang[2(✉)]

[1] AVIC (Chengdu) UAS Co., Ltd., Chengdu, China
[2] School of Aeronautics and Astronautics, Shanghai Jiao Tong University, Shanghai, China
miaowang@sjtu.edu.cn

Abstract. Unmanned aerial vehicles (UAVs) can carry out tasks such as border patrol and sea guard, which has a broad application prospect. How to apply intelligent technology in UAV system, so as to improve the efficiency of task execution in detection and route planning, has become a problem that needs to be studied. According to the application requirements, the intellectualization of UAV system can focus on three aspects, such as Intelligent detection and recognition, intelligent route planning and intelligent task planning. In this paper, the idea of systems engineering is applied and the modeling method based on DoDAF is adopted. First of all, the UAV task scenario model is established to specify the task activities that the UAV needs to complete in the scenario. Then, starting from the task scenario, the task architecture and system architecture DoDAF model of UAV intelligent system are established. Finally, the scenario model and DoDAF model are analyzed, and the capability catalog of UAV intelligent system is generated, which provides guidance for improving the intelligence of UAV system.

Keywords: DoDAF · UAV · Capacity demand

1 Introduction

In recent years, with the development of UAV technology, UAV has been widely used in border patrol and other industries [1]. UAV can carry out surveil-lance, reconnaissance, ground attack and other tasks, and can also be used for stability maintenance and anti-terrorism [2]. However, how to formulate the route of border patrol, and how to deal with emergencies such as detection of cross-border targets, are the difficulties facing UAV development. In order to solve the problems that UAV may encounter in patrol, it is necessary to improve the intelligence of UAV system.

The artificial intelligence of UAV system is now a hot research topic. Li[3] compared the effectiveness of UAV with intelligent system and UAV without intelligent system, but did not decompose the intelligent system into system-level analysis. Gucky [4] introduced AI into UAV control systems, but did not extend it to other systems. Hai [5] discusses how artificial intelligence (AI) can be used for unmanned aerial vehicle (UAV) monitoring, which is a good line of research, but not an intelligence upgrade within UAV systems. According to the existing research, to realize the intelligent UAV, we need to

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pay attention to obstacle avoidance technology, interactive technology, communication technology and so on.

To provide a reference for improving the intelligence degree of unmanned aerial vehicle system, we propose a method of generating a capability catalog of unmanned caerial vehicle intelligent system based on DoDAF. The research idea of this paper is shown in Fig. 1. First, a scenario model is established to preliminarily confirm the requirements for capability analysis of the UAV intelligent system. Then, the multi-perspective requirement analysis method based on DoDAF is adopted to model and analyze the UAV intelligent system. Finally, the capability catalog of the UAV intelligent system is generated. In the multi-perspective requirement analysis method based on DoDAF, the basic requirements are obtained based on scenario model analysis, and the preliminary requirement confirmation of capability is realized. Then, based on scenario model analysis, task activities are obtained, and the mapping relationship between capability and operational activities is established. The relationship between units is obtained by analyzing task activities, and the mapping of capability and organization is completed. Activities are then decomposed into systems to establish a mapping relationship be-tween capabilities and systems. Finally, the system resource flow is determined according to the system activities, and the metric value of capability is determined.

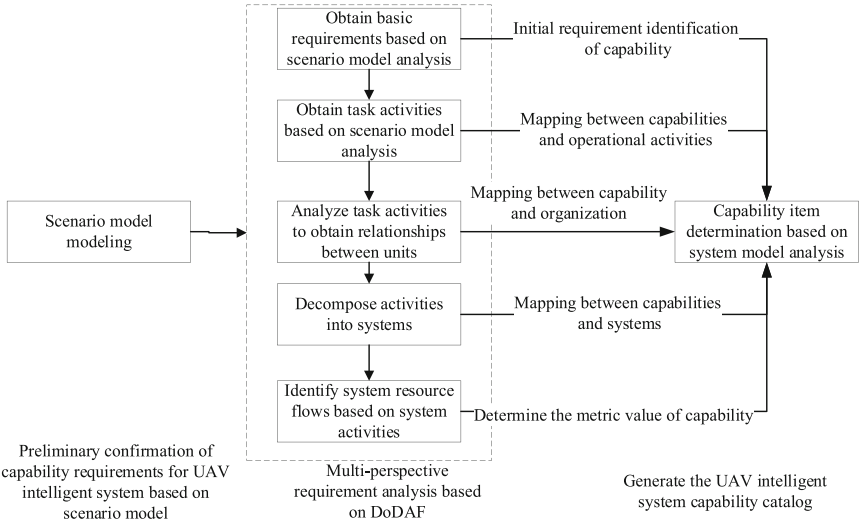

Fig. 1. Research idea of this paper.

2 Application Scenario Modeling and Demand Analysis of UAV Intelligent System

First of all, the content of the scenario is designed and the scenario model is established, which lays the application foundation for the subsequent model-based analysis and generation capability catalog. The blue objects represent our drones and the red objects

represent possible targets. According to the application of UAV, the sea patrol scenario of UAV is designed. The target is to patrol the rectangular area composed of “rp-10”, “rp-11”, “rp-12” and “rp-13”.The scenario model was built using a simulation scenario software named Origin, developed by Shareetech, as shown in Fig. 2. The specific scenario design is as follows: The ground control station determines the target of the sea patrol task, develops the task plan and uploads it to the UAV cluster. The drone receives the task plan and heads to the target area. Before reaching the patrol area, a drone detected a suspicious object. The UAV should be able to realize information transmission within the cluster and share information in the UAV cluster. In order to realize efficient detection, the UAV should have the capability of route change on board. Some UAVs rerouted their flight paths to detect and identify the target. The drone determines that the target is an unidentified flying object and transmits the detection information to the ground control station for further instructions. The UAV should be capable of identifying attack events and planning tasks on board. When the target is identified to attack us, complete the attack planning task on board.

Fig. 2. Application scenario model of UAV intelligent system.

According to UAV application requirements, UAV system intelligence can be focused on three aspects: Intelligent detection and recognition, intelligent route planning and intelligent task planning.

(1) Intelligent detection and recognition

If the UAV has the disadvantage of poor shooting effect, the photos are not conducive to subsequent automatic analysis [6]. If there is a disadvantage of poor recognition capability, it is difficult to identify signals or targets, it will get half the result with less effort [7]. Therefore, to improve the intelligence of UAV system, we should pay attention to the intelligent detection and recognition of UAV. Specifically:

a) The UAV should be able to realize the discovery and identification of attack events;
b) The communication radiation source of the signal can be located and error estimation on the UAV;
c) The UAVs can collect, find direction and identify patterns of ultrashort wave communication radio and other signals.

The detection and identification function of UAV is the basis for the realization of various applications of UAV. Through the intelligent upgrade of the detection and identification function, the detection task of UAV can be better completed and the application range can be expanded.

(2) Intelligent route planning

UAV route planning is particularly important in the patrol process, because the UAV route represents whether the UAV patrol is comprehensive. Once there is a problem in the route planning, the UAV cannot efficiently complete the work [8]. Existing UAVs often need ground stations to control the route [9]. In order to achieve intelligence, UAVs should have the route reconnaissance capability on the UAV, and can carry out dynamic route planning according to reconnaissance situation information, such as automatically avoiding routes according to the range of threat targets and realizing autonomous obstacle avoidance of UAVs. If the route planning of UAV can realize the autonomous planning on board, the maneuverability of UAV patrol can be greatly improved.

(3) Intelligent task planning

Since UAVs can perform various tasks such as surveillance, reconnaissance and ground attack, it is more important to pay attention to the task planning of UAS to improve the intellectualization of UAS [10]. In terms of hardware, intelligent task manager and intelligent task data recorder should be installed in the system. For example, if a ground attack task is to be executed, the aircraft must have the attack planning capability and replan the task based on the situation information. UAV task planning is the basis of UAV task execution. By intelligentizing task planning, the efficiency of UAV task completion can be improved.

3 Multi-View Requirement Analysis Method Based on DoDAF

After the scenario model is established, typical views in DoDAF are selected for modeling in order to facilitate subsequent demand analysis. DoDAF is a common architecture modeling method [11]. By establishing capability view, Operation view and system view, and improving task architecture and system architecture at multiple levels, the requirements of UAV intelligent system are analyzed. The DoDAF architecture modeling idea is shown in Fig. 3. Firstly, the capability architecture analysis is realized through the capability view modeling, and then the operational view is established based on the scenario model to realize the task architecture analysis. Finally, the operational view is decomposed to the system level, and the system view is established to realize the analysis of system architecture and physical architecture.

From the perspective of architecture design, 12 perspectives such as DoDAF architecture operational view and system view are selected to describe the model and construct the conceptual model, which is divided into 12 construction steps:

1) CV-2 is constructed to describe capability and its classification relationship;
2) CV-4 is constructed to describe the traceability relationship between capability items;
3) OV-1 is constructed to describe operational concepts, including tasks, task implementers, task sequence and interaction with external environment;
4) OV-4 is constructed to describe organizational relationship;
5) OV-5 is constructed to define the flow of Operation resources;
6) SV-4a is constructed to identify and decompose system functions;
7) SV-7 is constructed to describe the system measurement value;
8) SV-6 is constructed to describe the data exchanged between system functions and its characteristics;
9) SV-10c is constructed and event tracking is drawn;
10) SV-10b is constructed and the analysis of system logical state transition is drawn;
11) SV-1 is constructed to draw the interface lines of the system;
12) SV-2a is constructed to describe the logical connection between system nodes and systems.

The process of DoDAF-based multi-perspective demand analysis method is explained by selecting typical models in typical detection scenarios. The process is as follows.

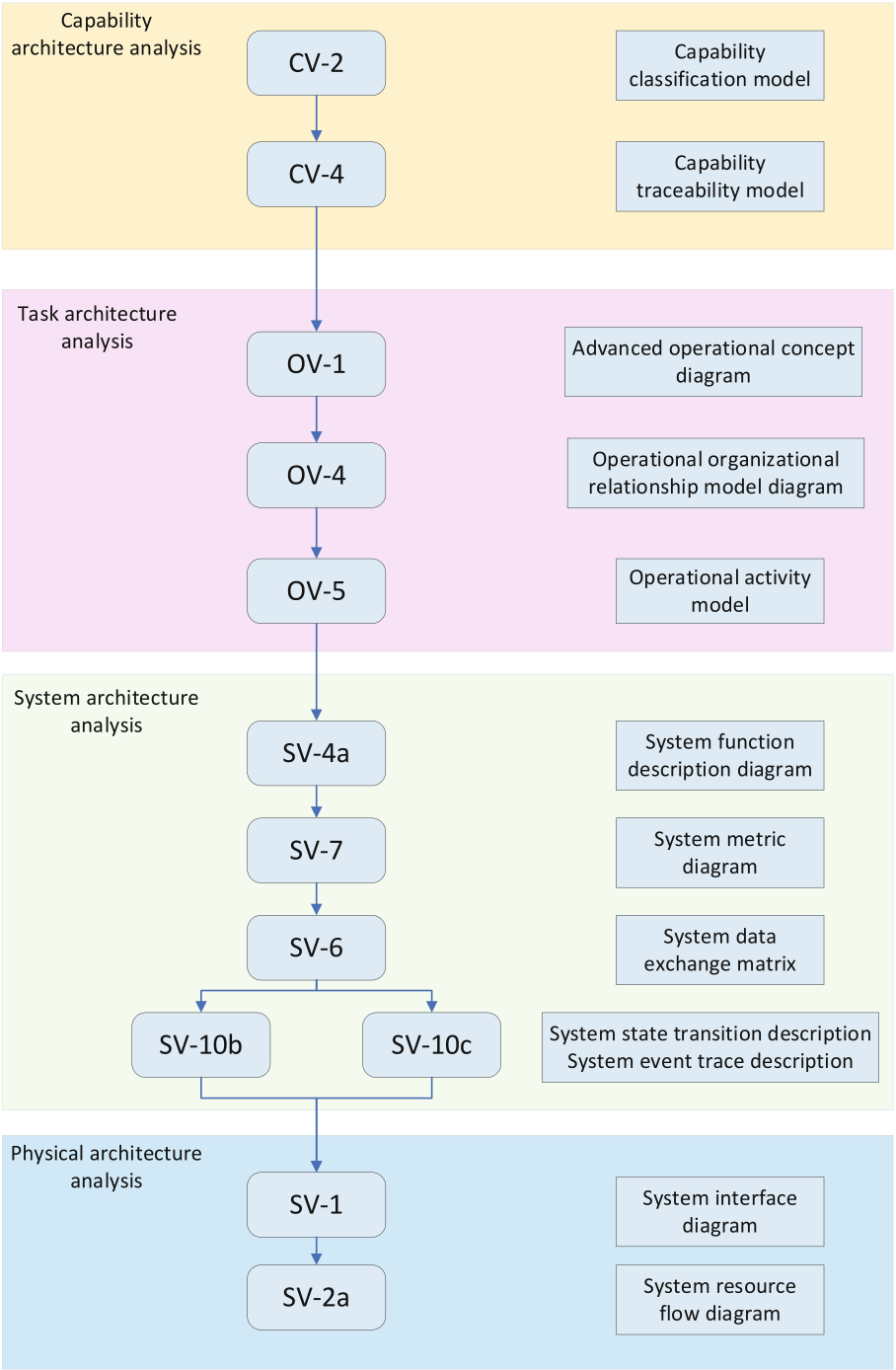

Fig. 3. DoDAF architecture modeling idea.

3.1 Basic Requirement Acquisition

Based on the scenario analysis of UAV intelligent system, capabilities are di-vided into six categories according to the classification idea of OODA ring [12], namely comprehensive perception capability, comprehensive identification capability, communication response capability, comprehensive defense capability, comprehensive strike capability and support capability. Establish the mapping relationship between intelligent system capabilities and OODA ring. Figure 4 shows the CV-2 capability classification model.

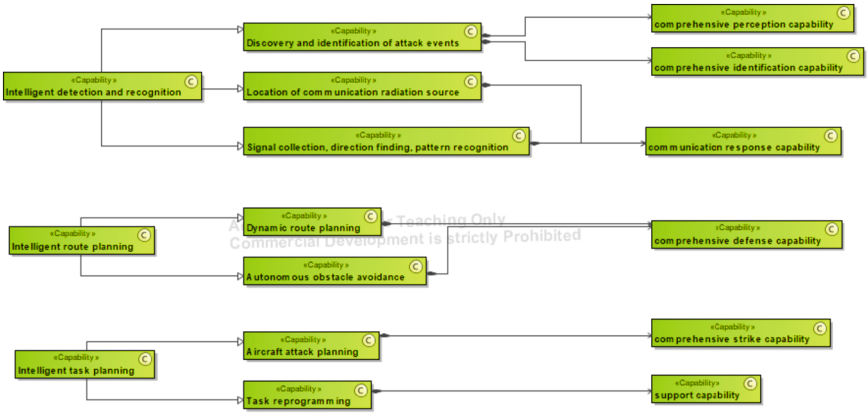

Fig. 4. CV-2 capability classification model.

According to CV-2 model, the basic requirements of capability can be defined, such as dynamic route planning, autonomous obstacle avoidance, etc. It is possible to specify the classification of capability items in the OODA ring.

3.2 Task Activity Acquisition

Then, according to typical application scenarios of UAV intelligent system (as described in Sect. 2, the activity transformation model is output, as shown in Fig. 5. The operational activity model describes the process of target detection through the cooperation of the ground station and UAV cluster.

After determining operational activities, the mapping model CV-6 between capability and operational activities is established, as shown in Fig. 6. As can be seen from the figure, dynamic route planning capability is related to flight route changing activities of UAV cluster. The capability to detect and identify attack events is related to the identification attack events of UAV cluster. Through the one-to-one correspondence between capabilities and operational activities, the specific application scenarios of each capability item can be defined, thus laying the foundation for determining the index value of capabilities.

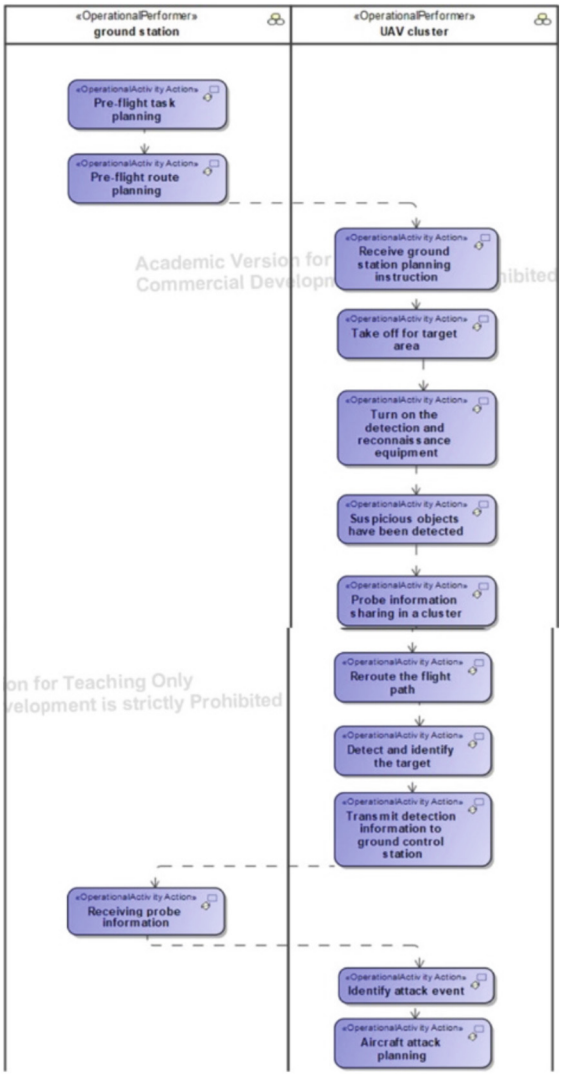

Fig. 5. OV-5 operational activity model.

3.3 Unit Organization Relationship Acquisition

In this step, the relationships between the units in the scenario are determined based on the Operation activity model. As can be seen from the analysis in Fig. 5, the ground station controls the UAV cluster and receives the detection information transmitted by the UAV cluster. And mapping the capabilities to the organization, all of which in this case is done by the UAV.

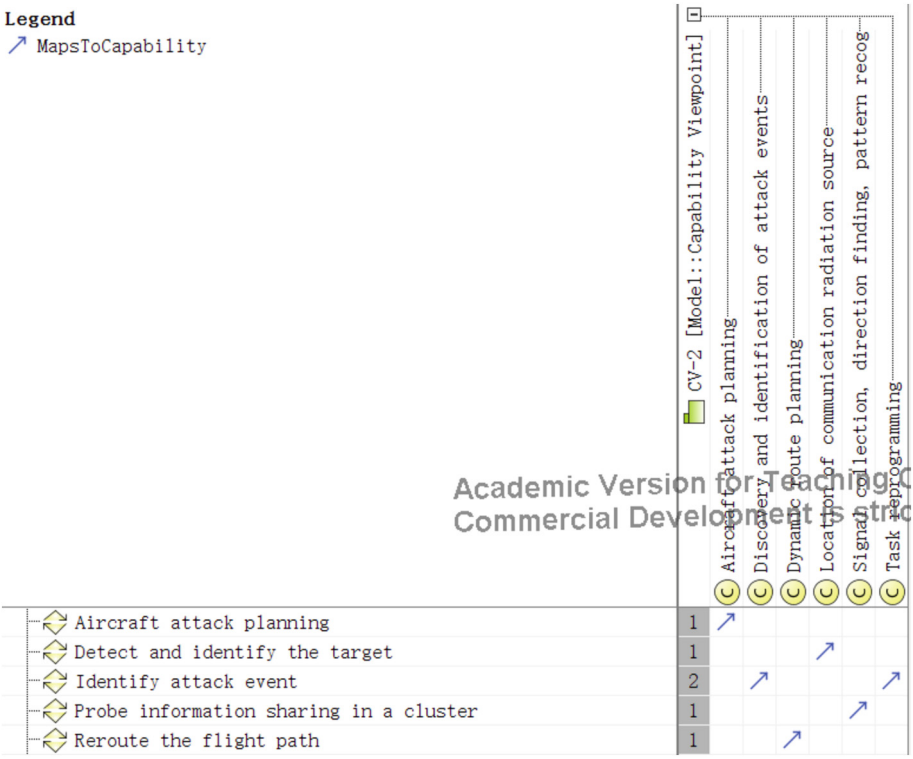

Fig. 6. CV-6 Mapping Model between Capability and Operational Activities (Part).

3.4 System Activity Decomposition

Operation activities are decomposed into various systems of UAVs so as to clarify the mapping relationship between capabilities and systems, as shown in Fig. 7. In the application scenario proposed in Sect. 3, the command is uploaded to the airborne link system of UAV after the ground station completes pre-takeoff task planning and pre-takeoff route planning. The drone takes off and turns on EO and SAR devices for detection. When the SAR device detects the suspicious target, the airborne link system transmits the detection information to realize the detection information sharing within the cluster. In the route planning module of the intelligent task Manager, the function of changing the flight route is realized. The Intelligent Task Data logger records relevant data. The detection related equipment carries out the detection task continuously, and transmits the detection information to the ground station by the airborne link system, and waits for the next instruction from the ground station. When the SAR recognizes that the target is attacking, the intelligent task management computer on the UAV completes the attack planning.

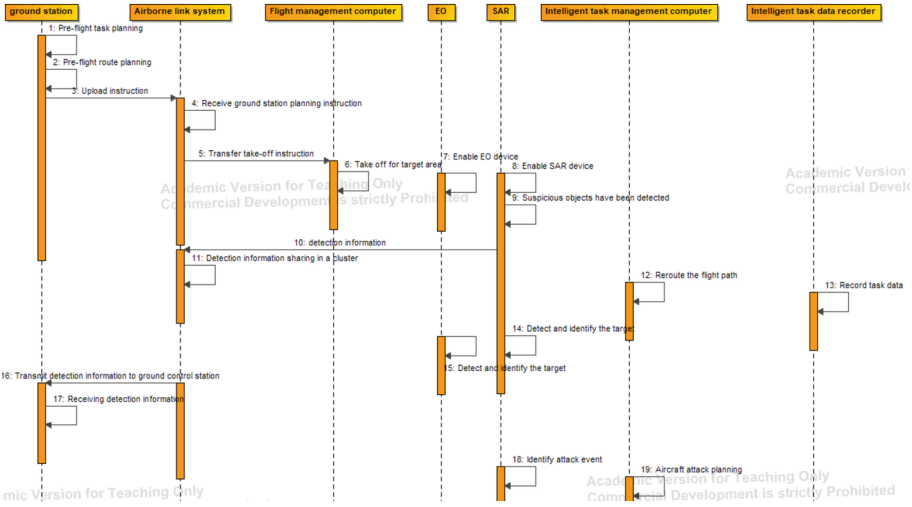

Fig. 7. SV-10c System timing diagram model.

After the Operation activities are decomposed into the system layer, the mapping relationship between capability and system can be determined, and the system function model SV-4 can be established, as shown in Fig. 8. Such as dynamic route planning, aircraft attack planning and other functions, need intelligent task management computer to achieve.

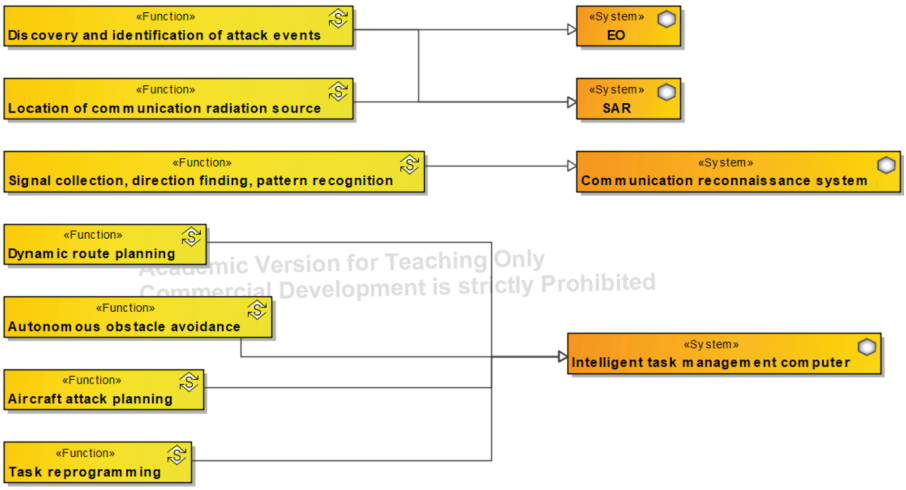

Fig. 8. SV-4 System function model.

3.5 System Resource Flow Identification

According to the activities between UAV systems, the typical resource flow between UAV intelligent systems is determined as shown in Fig. 9. The ground station uploads the control instructions to an intelligent task management computer in the drone. The intelligent task management computer sends the task data to the intelligent task data recorder for recording. EO transmits recognition information to the EO object recognition and detection module in the intelligent task data recorder. SAR transmits the detection information to the SAR target recognition detection module in the Intelligent task data logger. Communication reconnaissance system transmits identification information to the master software in the Intelligent Task data logger.

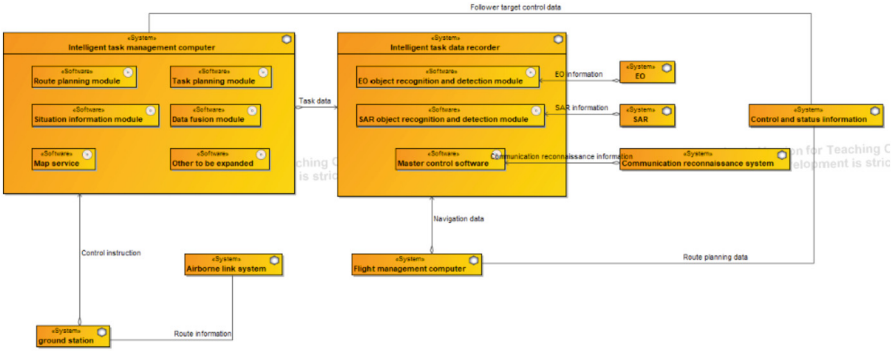

Fig. 9. SV-2a System resource flow model.

After determining the resource flow of the system, most of the modeling analysis process is completed. Finally determine a measure of capability, for example, to discover and identify attack events within 3 s.

4 UAV Intelligent System Capability Catalog Generation

According to the existing analysis results of scenario model and DoDAF model, the capability catalog of UAV intelligent system can be generated. Typical capability items are selected for description, as shown in Table 1. The capability catalog contains the capability classification, the specific content of the capability requirements and the matching relationship between the capability and the system. Take the capability to replan tasks based on situational information. It is a sub-item of intelligent task planning capability and related to intelligent task management computer system. Specifically, in order to achieve the capability of task replanning based on situation information, the task planning module in the UAV intelligent task management computer system needs to be upgraded to achieve the function of on-board task replanning.

By establishing the capability catalog of UAV intelligent system, the capability can be refined. The implementation of sub-level capability items to the system layer can provide reference for the research direction of system engineers and provide theoretical basis for the intelligent UAV system.

Table 1. UAV intelligent system capability catalog.

Number	Capability classification	Capability requirement	Related system
1	Intelligent detection and recognition	The capability to discover and identify attack events	SAR
2		The capability of the aircraft to locate and estimate the error of the communication radiation source of the signal	Communication reconnaissance system
3		The capability of collecting, direction finding and pattern recognition of ultrashort wave communication stations and other signals	EO
4	Intelligent route planning	Flight path reconnaissance capability, which means that dynamic route planning can be conducted based on reconnaissance posture information	Intelligent task management computer
5		Autonomous obstacle avoidance capability	Intelligent task management computer
6	Intelligent task planning	The capability to plan attacks	Intelligent task management computer
7		The capability to replan tasks based on situational information	Intelligent task management computer

5 UAV Intelligent System Capability Catalog Generation

In this paper, aiming at the requirements of system intelligence generated by UAV application scenarios, a typical application scenario of sea patrol is selected to complete the scenario description and establish the scenario model. Through the analysis of the scenario, the intelligent UAV system is determined in three directions: intelligent detection and recognition, intelligent route planning and intelligent task planning. Then, the multi-perspective requirement analysis method based on DoDAF is adopted to analyze

and build the model step by step according to the capability view, operational view and system view, and improve the measurement requirement and mapping relationship of the capability items. Finally, by analyzing the scenario model and DoDAF model, the capability catalog of UAV intelligent system is generated, which provides a theoretical basis for the intelligent UAV system.

The innovations of this paper are as follows:

(1) Three directions of intelligent UAV system are proposed, and the specific capability items produced by each direction are analyzed.
(2) Combine scenario model with DoDAF architecture model. First, the scenario model is established to determine the scenario of intelligent application of UAV. Then, the DoDAF architecture model of intelligent system of UAV is
(3) By analyzing the scenario model and the DoDAF architecture model of the UAV intelligent system, the capability catalog of the UAV intelligent system is established to provide a theoretical basis for the intellectualization of the UAV system.

The future work is to load the proposed capability item onto the UAV, and conduct the same task scenario simulation with the UAV without intelligent capability to verify the effectiveness and feasibility of the intelligent capability item.

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