Research on Digital Twin Framework of Military Large-scale UAV Based on Cloud Computing

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Abstract: Firstly, this article explains the characteristics and advantages of military large-scale UAVs, and points out the three basic problems currently encountered by military large-scale UAVs; secondly, this article is based on the current design, manufacturing and application reality of large-scale military UAVs, analyzed the urgent need to build a cloud computing-based digital twin framework for military large-scale UAVs, and discussed in detail from the aspects of test cost, integrated perception, centralized control, business prediction, and mission planning; again, this article proposed cloud-based computing The digital twin framework for military large-scale UAVs discusses the composition and functions of each layer; finally, it points out the five directions and work priorities that need to be paid attention to in the construction of the digital twin system of military large-scale UAVs, including UAV model, flight status measurement, reliable propagation channel, intelligent command and control, and capability evaluation analysis.

1. Introduction
As an intelligent means, UAVs are promoting the intelligent upgrading of traditional industries. They are highly intelligent, highly maneuverable, long-lasting, high-load capacity, high safety, low construction and operation and maintenance costs, which will effectively make up for traditional manned aircraft. The shortcomings of other methods will bring new breath to the future battlefield and various civilian industry applications [1]. Large military UAVs have the advantages of high flying height, wide coverage area, long working hours, flexible use, and low operating cost. They have become an ideal aerial platform for tasks such as intelligence, reconnaissance, surveillance, and communication relay. It has the following Features: ① big load and stable performance parameters; ② strong maneuverability and short attack time; ③ controllable operation and zero casualties [2]. Large-scale military UAVs can conduct coordinated reconnaissance in multiple dimensions, in multiple directions, in multiple batches, and for a long time. It can effectively expand the scope of reconnaissance, expand reconnaissance elements, improve reconnaissance accuracy, and dynamically track targets, which can significantly improve reconnaissance effects. Covering all aspects of control, strike, communication, navigation, electromagnetic and network attack and defense, is an important direction for the development of UAV combat systems. In the context of high-tech local wars informatization, networking, intelligence, and unmanned, multi-system distribution and coordinated operations based on large UAVs will be a frontier development direction for local wars in the future. At present, the construction of multi-task scenarios, virtual-real interaction channels and virtual model driving for military large-scale UAVs are three basic issues. Large-scale UAV body model construction, perception integrated presentation, virtual-real collaborative control, payload business prediction, and network collaborative planning are carried out. Research in other aspects is imminent [3].
2. Demand for cloud-based digital twin technology
Currently, large military drones have the following five requirements for cloud computing-based digital twin systems:

2.1 The complex structure of the airframe is high in flight test costs, and cloud computing is urgently needed to reduce costs and increase efficiency.
As a complex large-scale system, military large UAVs include airframe structure, power system, avionics system, flight control system, electrical system, integrated energy management system and mission load systems[4], the system structure is complex and the body assembly is complicated. The component reusability is not strong, the test flight cost is high, and cloud computing technology is urgently needed to realize the motion simulation, assembly simulation and performance simulation of complex products. The virtual test of the digital prototype can reduce the cost of physical prototype and physical test, thereby reducing The cost of human-machine R&D and trial production will improve the R&D efficiency of large military drones. The more complete the digital twin model of the military large-scale UAV based on cloud computing is, the more it will be able to approach its corresponding entity object, so as to visualize, analyze and optimize the entity object.

2.2 The real-time performance of body information synchronization perception is poor, and cloud computing integrated perception is required.
Due to the long-term cruising of military drones at the bottom of the stratosphere, special use environments such as high altitude and low air pressure, low temperature, solar radiation, ozone, cosmic rays, increase with altitude, and the atmospheric pressure decreases and the density decreases, which brings damage to aircraft and flight many influences: ① Low air pressure will have a certain impact on the body structure and airborne equipment. The refilling temperature will decrease with the increase of the flying altitude. The low temperature has an adverse effect on almost all the base materials. ② Solar radiation will also produce photochemical effects, causing certain damage to equipment. The most affected materials are non-metallic composite materials, including plastics, rubber, and textile fibers. ③ The high-altitude cosmic radiation is strong, and these high-energy neutrons have strong penetrating power, which will cause the safety level of airborne electronic equipment to degrade and affect the use of drones. All of these require real-time monitoring of drone body information to deal with uncertain situations that come at any time. However, current large-scale military drone mission monitoring is mainly based on video monitoring and two-dimensional configuration software monitoring, and its shortcomings are mainly manifested. Due to the poor intuition and analysis ability, the large amount of transmission data and the occupied bandwidth, and the poor effect due to the harsh environment, it is urgent to rely on the mature monitoring method of cloud computing technology to realize the real-time status perception of the long-term flight of military large UAVs.

2.3 The air-ground coordinated control is not precise, and cloud computing centralized control is required.
The task of large-scale military drones is relatively single. During the flight, a series of flight states such as climb, cruise, and descent are required. The flight speed and altitude vary greatly. Therefore, the air density and dynamic pressure of the flight environment are uniform. Great changes will follow, and its flight trajectory will also be inconsistent due to different mission requirements, making coordinated control difficult. Due to the low requirements for control performance and the limitation of hardware conditions, classical control theory and traditional control systems can only be used for control. With the increasingly complex structure of military large-scale UAVs, the increasingly diverse mission load equipment, the higher and higher control performance requirements, and the larger flight envelope. With the changes in flight status and external disturbances, the parameters of the system vary widely, and classical control theory alone cannot meet the requirements of control performance [6]. There is an urgent need for cloud computing environment to realize autonomous flight control of hierarchically decomposed control structure, accurately control flight attitude, rudder speed and other
indicators, and realize the integration of multiple tasks such as active control, adaptive control, stability enhancement control, and automatic flight control technology [7].

2.4 Load operation forecast lacks means, and cloud computing business forecast is required.

The basic feature of digital twin technology is virtual and real mapping, which can realize the two-way mapping between physical model and cloud computing model by constructing cloud computing model for physical entities. The mission load of solar unmanned aerial vehicles in the near space can take many different forms according to different tasks, including photovoltaic cameras, infrared cameras, synthetic aperture radars, laser rangefinders, etc., according to the body structure model, atmospheric radiation transmission model, photovoltaic conversion Models, etc. model the load [8], combined with other cloud computing models of military large-scale UAVs to form a digital main line to predict load capacity. The digital main line can not only string together the digital twin models of various stages of design, testing, and application, but also include information about the entire product life cycle to ensure the consistency of various product information when changes occur. This application mode will greatly broaden the application range of military large-scale UAVs, thereby improving their work efficiency in wide-area reconnaissance, communication relay, cooperative detection and other mission scenarios [5].

2.5 The efficiency of virtual and real networking collaboration is low, and cloud computing collaborative planning is required.

The cloud computing-based digital twin model is not an end, but a means. It is necessary to analyze and optimize the model to improve the performance and operating efficiency of its corresponding physical entity. In the scenario of performing multi-aircraft cooperative tasks, large military UAVs need functions such as “obstacle avoidance” and target recognition for route planning, and need to interact with the ground control station [6], and can be pre-installed according to changes in external conditions. Adjust the flight trajectory based on the reference trajectory. In the case of formation flying, it meets the design conditions of low speed, high torque, light weight and high efficiency at the same time, can coordinate the task assignment of the formation and the ability to find the optimal route of the formation, and control the execution layer to complete the military large-scale UAV and mission. Set up real-time control of the load, mainly controlling its flight path, heading, attitude, etc., combined with the functional characteristics of the load itself, to achieve automatic tracking of the locked target, and comprehensive coordinated planning of the motor, propeller, ESC and reducer at the system level, UAVs are inevitably affected by various external disturbances during the flight, ensuring the robust stability of the flight control system, so that the reasonable matching of various components reaches the overall optimal [9].

3. Digital twin framework for military large drones

As shown in Figure 1, the digital twin technology based on the cloud computing platform is used to realize the virtual and actual interaction of military large-scale UAVs, and build an overall support platform for modelling of the airframe structure, modeling of supporting systems, unification of data sources, and cross-regional collaboration to promote networking, informatization and intelligentization of large-scale military UAV system engineering [10].

3.1 The basic support layer.

Including the network, computing, storage and management facilities, ensures that the number of data channels, sampling frequency, and data resolution of large military UAVs are consistent with the actual test, through the use of sensors and airborne measurement and control equipment. Obtain data from physical test data, realize airframe flight data collection, cleaning, screening, analysis, fusion, storage, analysis and presentation, and big data movement and backup [10], supporting upper-level services and applications.
3.2 Digital twin layer. Composed of distributed resource nodes, it mainly carries cloud computing and data interaction bus operation, and provides online self-service arrangement and assembly. It is used in the flight control computer, flight control calculation interface box, electric steering gear, tail, Landing gear, on-board battery and other physical objects, construct all the information of the airframe design, component technology, component attributes and other information are attached to the three-dimensional model, and realize the definition of the airframe envelope, constraints, annotations, engineering attributes and hierarchical structure [11]. As well as standardized defined interfaces, a digital twin platform is constructed to reduce the coupling of airframe modules and related systems, and integrate cloud computing to build system level, aircraft and surrounding environment level, aircraft body level, component level, part level and other multi-level resolution verification Environment to realize seamless docking and system integration of heterogeneous system data flow.

3.3 The collaborative control layer, which is composed of different control systems supporting large military UAVs, including energy, flight attitude, flight remote control/telemetry simulation, flight command and control, structural health monitoring and display subsystem, as well as ground station control terminal and power supply System modules, flight control modules, power system modules, energy management control modules and sensor modules, etc., dynamically perceive the current status of virtual/real UAVs, dynamically couple various systems, and form fact monitoring and control capabilities.

3.4 The task coordination layer, including the drone body, edge computing nodes, flight control nodes and on-board high-speed network, is mainly based on the decisions made by the ground control station to control the aircraft to adjust its attitude, heading, and speed, fly according to the planned track, and cooperate Relevant task loads perform tasks [12].

3.5 Through the cloud computing-based digital twin platform, it can be divided into system level, aircraft and surrounding environment level, aircraft body level, component level, part level and other multi-level resolutions for research according to the granularity of UAV components. All the data, models, and algorithms involved in the component modules of each level of resolution are encapsulated into different sub-services, and these sub-services are associated to form higher-level services that meet the needs of the application. It can be automatically associated through a well-defined digital twin interface protocol to make the entire digital twin system architecture faster, more reliable, and more reusable.

4. Suggestions for the construction of a digital twin system for large military drones
Now is the bursting period for the development and application of smart terminals. Large military drones will be applied to various fields. This has become a major trend in the development of military technology, and is developing in the direction of higher mobility, lighter and more durable, and stronger intelligence. With the continuous maturity of intelligent manufacturing technology, the design, manufacturing, testing and application of large military drones based on cloud computing will soon form a closed loop. At present, there is an urgent need to combine advanced measurement, transmission, control, and evaluation technologies and methods to construct a flight cloud computing system to achieve the full life cycle simulation simulation of military large-scale UAV demonstration design, module trial production, experimental verification, and mission application[13]. Forming a multi-domain, full-dimensional, and strong real-time complete closed loop of "collection-transmission-control-evaluation" for large military UAVs, realizing the interaction and integration of physical space and information space. Aiming at building strong digital, informatized, intelligent, and diversified military large-scale UAV construction needs, we need to focus on the following points:
4.1 Complete UAV model construction.
①Ontology model set: including UAV body structure model, component function model, component electrical model, component failure symptom model, etc. ②Environment Model set, including typical high-altitude weather environment, space electromagnetic environment, counter electromagnetic environment, etc. ③Network model set, single aircraft air-ground networking coordination model, multi-aircraft task coordination model, sky-air-ground long-distance coordination model, etc.

4.2 Accurate flight status measurement.
Based on the UAV model system, the airborne edge micro-cloud is used for real-time differential analysis of real-time measurement data [15]: ①Positioning measurement analysis, a high-precision positioning measurement analysis method based on carrier differential, forming a large sub-decimeter dynamic error Regional position, speed and heading conclusion data, and download it in real time; ②Attitude measurement analysis, based on the analysis of multi-dimensional fine sensor data such as altitude, roll angle, yaw angle, vibration, etc., through differential analysis to form flight parts status information, effectively reducing the body attitude accurately measure the error, and download incrementally; ③Electrical measurement analysis, based on electrical component measurement data, form component status information through differential analysis, effectively reduce the accuracy of the body attitude measurement error, and incrementally download it.

4.3 Build a reliable propagation channel.
Based on mature asymmetric and symmetric encryption algorithms, combined with emerging blockchain technology, develop: ①Trusted authentication, PKI-based digital signature identity authentication architecture, to realize the trusted identification of the master station and single and multi-machine identity; ②Security Channel, based on the data symmetric encryption of the proprietary instruction set of the domestically produced processor platform, proposes an effective proprietary IP communication protection protocol to form a secure and confidential transmission channel; ③Reliable control, based on blockchain technology, constructs a one-time encryption The reliable interactive system of flight control commands forms a reliable control of the UAV.

4.4 Supporting intelligent command and control
①Basic flight control, based on flight control quality and body response data, through regression algorithm for machine learning training to form a command-action correlation data set for flight control prediction; ②Environmental adaptation control, machine learning formation through naive Bayes algorithm Environment-body response data set, used for environment simulation prediction; ③Task response control, machine learning through decision tree algorithm to form task-response data training, used for task decision control assistance.

4.5 Strengthen capacity assessment and analysis
①Airframe structure evaluation, combing and forming a set of quantitative indicators for component strength attenuation, electrical device aging, and power system attenuation, so as to realize automatic evaluation of the body composition structure;②Networking collaborative evaluation, simulating network connection, transmission bandwidth, connection delay, and access efficiency, Response rate, etc., to form an automated evaluation capability for network coordination capabilities; ③Load business evaluation, collaborative operation prediction based on load business capability modeling, to form an automated evaluation capability for load business. Based on the above evaluation, it provides a reference for the continuous optimization of the aircraft.

5. Summary and outlook
This article discusses the necessity of building a cloud computing-based digital twin framework for
military large-scale UAVs from the aspects of test cost, integrated perception, centralized control, business prediction, and mission planning. Strengthen research on flight status measurement, reliable propagation channel, intelligent command and control, and capability assessment analysis, and promote the construction of military equipment digital twin model, cyber-physical data fusion, interaction and collaboration through cloud computing-based digital twin framework construction for military large-scale UAVs. The application hopes that the related twin data, domain knowledge and its fusion data can provide reference for the design, production, testing and operation and maintenance of unmanned equipment with many other components, complex structure and high real-time requirements.

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