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Feasibility Analysis of the Application of Artificial Intelligence Technology in the Airworthiness System of Unmanned Aerial Vehicles

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Abstract

The airworthiness system is a series of standards and procedures to ensure the safe operation of unmanned aerial vehicles (UAVs), and the introduction of artificial intelligence technology is expected to improve the efficiency of UAV design, operation, and maintenance, thereby enhancing its safety. Therefore, studying the application of artificial intelligence technology in the airworthiness system of unmanned aerial vehicles has important theoretical value and practical significance. This article conducts an in-depth study on the feasibility of applying artificial intelligence technology in the intelligent development direction of unmanned aerial vehicle airworthiness system. Conduct a technical evaluation of the application of artificial intelligence technology in the unmanned aerial vehicle (UAV) airworthiness system by examining cases of existing AI technology in the traditional airworthiness field and exploring the possibility of applying related technologies; Finally, summarize the current development status of unmanned aerial vehicle airworthiness intelligence and analyze the feasibility of applying artificial intelligence technology in the unmanned aerial vehicle airworthiness system.

Keywords

UAV, Airworthiness of Unmanned Aerial Vehicles, Artificial Intelligence Technology, Airworthiness Intelligence

1. Introduction

In the past few decades, drone technology has expanded from the military field to civilian and commercial applications, widely used in logistics, monitoring, agriculture, photography, and other fields. With the advancement of technology and the expansion of application fields, drones have shown tremendous potential for development and application prospects. However, the widespread use of drones not only brings enormous potential and convenience to various industries, but also poses increasing challenges to traditional airworthiness systems, urgently requiring the intervention of new technologies to improve their efficiency and safety. How to avoid collision accidents and other risks to ensure the safe flight of drones, how to effectively manage airspace, and how to adapt to constantly updated technological and regulatory requirements have become important issues that the industry and regulatory agencies must face.

As a powerful tool in contemporary times, artificial intelligence's abilities in data processing, pattern recognition, and autonomous decision-making provide possibilities for the innovation of unmanned aerial vehicle airworthiness systems. In addition, the Chinese government has released a draft of the "Interim Regulations on the Flight Management of Unmanned Aerial Vehicles" for comments, which clarifies the classification and management requirements for civil drones, especially the airworthiness management of medium and large drones. This indicates that with the development of the drone industry, the trend of international standardization is becoming increasingly evident, and regulatory measures are constantly being strengthened. By comprehensively considering technological maturity, cost-effectiveness, laws and regulations, and society.

This study will provide theoretical support and practical guidance for the innovation and sustainable development brought by artificial intelligence technology to the drone industry, which will affect multiple dimensions.

2. Airworthiness Certification of Aircraft Model Design

In the field of civil aviation, airworthiness certification is a crucial step in ensuring the safe operation of aircraft. It involves the entire process from aircraft design, manufacturing to final operation, aiming to ensure that the aircraft meets the minimum safety standards. The certification technology for aircraft model design in airworthiness management mainly includes key technical areas such as design safety assessment, electromagnetic compatibility analysis, environmental testing and protection.

In the second part of the "Civil Unmanned Aerial Vehicle System Airworthiness Certification Management Procedure", the risk-based design approval principle is stated that the risk-based principle is adopted in the design approval work and classified management is implemented. And safety assessment is the core part of risk classification. According to the "Airworthiness Safety Guidelines for Civil Unmanned Aerial Vehicle Systems", a detailed list of safety assessment subjects indicates that safety assessment involves comprehensive considerations of aircraft design, performance, and operation, and is necessary to ensure the safety of the aircraft throughout its entire service life.

With the increasing number of aviation electronic devices, electromagnetic compatibility has become an important consideration in aircraft design. Electromagnetic compatibility analysis is conducted to ensure that electronic devices on aircraft can operate normally without interference in the electromagnetic environment they are in. The analysis includes analyzing and testing various electromagnetic sources inside and outside the aircraft to prevent electromagnetic interference from affecting the safe operation of the aircraft.

The design and verification of fire prevention systems are important components in ensuring the safe operation of civil aircraft[1]. The fire prevention system includes functions such as fire detection, monitoring, alarm, and extinguishing, and its purpose is to protect the safety of the aircraft and its passengers in the event of a fire. By conducting professional fire protection design and rigorous testing verification on key areas of the aircraft such as the engine compartment, cargo hold, and APU compartment, it is possible to ensure that the fire protection system can quickly and effectively intervene in emergency situations, thereby minimizing potential fire risks to the greatest extent possible.

Environmental testing is a crucial step in testing whether an aircraft can operate safely under various extreme weather and climate conditions. By conducting a series of environmental tests such as high temperature, low temperature, humidity, vibration, and impact on the aircraft and its systems, it is ensured that the structure, systems, and equipment of the aircraft can operate normally under specified environmental conditions. At the same time, it is necessary to carry out protective design for the aircraft, such as lightning protection, corrosion prevention, etc., to improve its durability and reliability.The following Figure 1 shows the modeling, simulation, and testing platform for safety system failures

Figure 1. (Airworthiness certification laboratory for avionics system safety) Safety system failure modeling, simulation, and testing platform.

Based on the research of typical avionics equipment fault injection methods, the avionics system safety airworthiness certification laboratory has built a semi physical failure simulation environment and conducted interactive analysis of test data and model simulation data after the integration of aviation materials. This has formed a complete aircraft closed-loop simulation system, providing technical support for aircraft and system safety airworthiness certification.

As modern aircraft increasingly rely on advanced software and hardware systems, ensuring the reliability and safety of these systems has become an important aspect of airworthiness certification. According to international standards such as DO-178C and DO-254, strict supervision is carried out on the development process of aviation electronic software to ensure that every stage of software development meets airworthiness requirements. At the same time, design, test, and validate the onboard hardware to ensure that it meets relevant performance and safety standards.

3. Airworthiness Certification for the Production Quality of Aviation Components

Airworthiness management not only involves the overall design and performance of aircraft, but also includes strict monitoring and certification of the production quality of all its components. The Chinese Civil Aviation Regulations "Certification Regulations for Civil Aviation Products and Components" (CCAR-21-R4), which came into effect on July 1, 2017, provide sufficient explanations for the airworthiness certification content of "production approval". The following will delve into the key technologies of aircraft component production quality certification in airworthiness management.

The production process of aviation components must strictly follow established quality standards and procedures. Airworthiness management departments usually conduct reviews of production facilities to ensure that they have appropriate production equipment, process equipment, and testing tools. At the same time, key quality control points in the production process will be monitored, such as material selection, processing accuracy, heat treatment, and surface treatment, to ensure that the produced components meet design and performance requirements.

CCAR-21-R4 proposes in Article 21.137 "Quality System" inspection and testing procedures to conduct flight tests, engine and propeller function tests, and other content as quality system standard requirements for civil aviation manufacturers. Aviation components need to undergo a series of quality inspections and tests before delivery to verify their compliance with airworthiness standards. This includes size measurement, non-destructive testing, functional testing, and environmental stress screening [2]. Through these tests, it can be ensured that the components can maintain their performance and reliability even under various conditions that may be encountered during actual operation.

The production of aviation components involves a wide range of supply chain systems. The airworthiness management department requires manufacturers to establish an effective supply chain management system to ensure that all materials and components provided by suppliers comply with airworthiness standards. This includes the evaluation, selection, and monitoring of suppliers, as well as regular reviews and confirmations of their product quality.

Even if aviation components have obtained airworthiness certification, the airworthiness management department will continue to supervise and review them. According to Appendix H of CCAR-25, the continuing airworthiness documents for aircraft must include: continuing airworthiness documents for engines and propellers (hereinafter referred to as "products"), continuing airworthiness documents for equipment required by Chinese civil aviation regulations, and necessary information on the interconnection between these equipment and products and the aircraft. This fully demonstrates the emphasis on the word 'always' in the airworthiness of civil aircraft.

Through regular audits, inspections, and testing, it can be ensured that components maintain consistent quality standards throughout their entire lifecycle. At the same time, manufacturers will be encouraged to adopt advanced technologies and methods, continuously improve their design and production processes, in order to enhance the quality and performance of their products.

4. The Application of Artificial Intelligence Technology in Airworthiness Certification

Airworthiness certification mainly focuses on the design and production process of aircraft, risk and safety assessment of unmanned aerial vehicle system operation, modeling and simulation testing of civil aircraft operation scenarios, and fault diagnosis of aviation mechanical equipment.

The development of artificial intelligence technology has provided new ideas and methods for the airworthiness certification of civil aircraft. Through efficient data processing and analysis capabilities, artificial intelligence technology can not only improve the accuracy and efficiency of safety assessments, help predict and prevent future safety risks, but also analyze real-time monitoring of aircraft status data and diagnose system failures in real time. Artificial intelligence technology provides strong support for the safe operation of aircraft. Below are some specific examples of the application of artificial intelligence technology in airworthiness certification.

The "Guidelines for Classification and Safety Analysis of Civil Unmanned Aerial Vehicle System Airworthiness Certification" points out that the risk and safety assessment of unmanned aerial vehicle system operation is often carried out using fault tree analysis models, which has a certain negative impact on the risk level classification management mode of unmanned aerial vehicle airworthiness. Regarding the traditional security model Fault Tree Analysis (FTA), although it is easy to understand and widely applied, there may be unforeseen failure modes or incorrect logical relationship settings. Reference [3] takes the aircraft fuel distribution system as an example and proposes an algorithm for optimizing safety models using AI, which mainly involves the following steps and strategies.

Firstly, by collecting real-time operational data of the system, we can understand the behavioral patterns of the system during normal operation. This includes collecting data from multiple sensors, such as temperature, fuel level, and other relevant parameters. Use machine learning methods (such as One Class Support Vector Machine, OC-SVM) to analyze real-time data to identify any deviations from normal behavior patterns. When a new monitoring dataset arrives, AI will compare it with a pre generated normal behavior model to detect abnormal behavior.

Once abnormal behavior is detected, AI will analyze the correlation between the behavior and different parameters in the system to determine which factors may have caused the occurrence of abnormal situations. For example, by analyzing the relationship between temperature changes and reduced fuel flow, it can be inferred that abnormalities may be caused by pump or valve failures. Based on the detected anomalies and correlation analysis results, the system will propose a series of possible repair measures or update suggestions according to the preset logic and rule library. This may include adding new basic events to the fault tree, or correcting incorrect settings of logic gates in the fault tree to more accurately describe system behavior.

If the existing fault tree cannot explain the detected abnormal behavior, the AI system will suggest correcting the fault tree. For example, it may be suggested to replace the AND gate with an OR gate to improve the interpretability of the model.

In summary, the optimization of the security assessment model has improved the accuracy of China's operational risk-based security assessment model and the efficiency of risk classification management.Figure 2 below presents the framework of the AI anomaly detection and warning notification method proposed in reference [3].

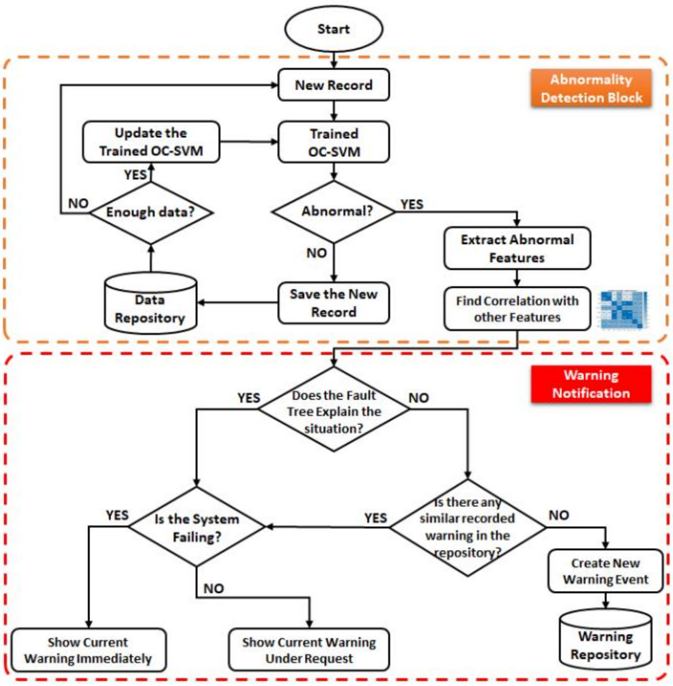

Figure 2. AI anomaly detection and warning notification method framework proposed in reference [3].

Artificial intelligence technology has also been widely applied in the modeling and simulation testing of civil aircraft operation scenarios. In the process of building safety system failure modeling, simulation, and testing platforms, the integration of digital modeling and AI can be achieved based on AI's data processing capabilities[4]. The efficient processing and analysis capabilities of artificial intelligence technology have improved the accuracy and efficiency of simulation testing on simulation platforms in the following aspects.

By utilizing machine learning and deep learning algorithms, artificial intelligence can analyze large amounts of historical data to identify potential failure modes and influencing factors. By deeply mining these data, artificial intelligence can predict the possible failure situations that the system may encounter in the future, providing scientific basis for aircraft design and improvement.

By collecting real-time operational data of aircraft systems, artificial intelligence can detect abnormal situations in real time and automatically adjust system parameters or issue warnings to avoid potential safety risks. This real-time monitoring and dynamic adjustment capability is crucial for ensuring the safe operation of aircraft in complex environments.

Artificial intelligence technology can automate complex modeling and simulation tasks, such as simulating the failure behavior of aircraft systems through neural networks or optimizing the design of flight systems using genetic algorithms [5]. Through cloud computing and distributed computing technology, artificial intelligence can parallel process large-scale modeling and simulation tasks on multiple computing platforms. In summary, these methods not only improve the efficiency of modeling and simulation, but also enhance the accuracy and reliability of results, greatly shorten the aircraft development cycle, and accelerate the process of launching new aircraft models.

The application of AI in mechanical equipment fault diagnosis is mainly reflected in the empowerment of deep learning. To achieve the goal of device fault detection, data is first collected through remote monitoring of devices using IoT technology, and then advanced deep learning algorithms are used to automatically extract features from massive data, and these features are analyzed and classified in depth to identify potential fault modes [6]. Convolutional neural networks (CNNs) are widely used in fault diagnosis, such as classification of bearing faults, due to their excellent image processing and feature learning capabilities. The application of convolutional neural networks has improved the accuracy and efficiency of fault diagnosis. Generative Adversarial Networks (GANs) use their data generation capabilities in unsupervised learning environments to help models learn more diverse and abundant fault data, thereby improving the accuracy of fault detection. Autoencoder (AE) is also an unsupervised learning method that learns compressed representations of data by reconstructing input data, effectively capturing the intrinsic structure of the data. This network is also suitable for diagnosing various types of faults. Deep belief networks (DBNs) abstract complex features from data layer by layer by constructing multi-layer learning models, providing an effective solution for fault diagnosis [7].

By combining IoT technology, these deep learning models can remotely receive real-time operational data from devices and quickly provide feedback and analyze results, greatly improving the efficiency and accuracy of fault detection. Through this highly integrated approach, precise monitoring and management of the health status of mechanical equipment can currently be achieved, in order to optimize maintenance strategies and reduce operational costs.

In the initial airworthiness management of civil aircraft, the main management object is the design and production process of the aircraft. At present, the most advanced intelligent manufacturing technology for aircraft assembly includes the integration of digital twin (DT) and artificial intelligence (AI) [8].

The application of digital twin technology in aviation intelligent manufacturing is mainly manifested in its ability to create a virtual model that corresponds to the actual production environment. The application of artificial intelligence technology in aviation intelligent manufacturing is more extensive, including but not limited to process planning, quality control, resource scheduling, and other aspects. AI technology can process large amounts of data, automatically complete complex decision-making processes through learning and reasoning, thereby improving the intelligence level of manufacturing processes. In the intelligent manufacturing of aircraft assembly, the integration application scenarios of DT (digital twin) and AI (artificial intelligence) in aviation intelligent manufacturing mainly include the following aspects:

By combining digital twin technology and artificial intelligence, real-time monitoring and adaptive control of aircraft assembly processes can be achieved to improve production efficiency and quality. This fusion application can dynamically adjust production parameters and optimize production processes based on actual production conditions.

By utilizing digital twins and artificial intelligence technology, intelligent management of aircraft assembly workshops can be achieved, realizing automation, informatization, and intelligence of the production process. This includes real-time data collection, analysis, and decision support, as well as exploring data-driven production control models[9].

By integrating digital twins with artificial intelligence, it is possible to effectively schedule and optimize manufacturing resources. This involves the optimal allocation of manufacturing resources, optimization of production plans, and resource allocation issues in the production process.

By combining digital twin and artificial intelligence technology, intelligent control of product quality during aircraft assembly can be achieved. This includes utilizing AI for predicting, diagnosing, and generating solutions to quality issues, as well as simulating and optimizing quality control processes through digital twin technology.

By integrating advanced intelligent equipment systems, the automation and intelligence of aircraft assembly processes can be achieved. This includes the design of an intelligent collaborative management platform, independent research and development of intelligent equipment products, and the generation of intelligent logistics transportation and management systems, thereby promoting the development of aircraft intelligent manufacturing towards engineering applications[10].

The integration of digital twin technology and artificial intelligence technology has achieved intelligent manufacturing of aircraft, which is a leap forward in the productivity of the aviation industry. The excellent ability of artificial intelligence technology to analyze data and extract image features perfectly conforms to the development of the digital age. The intelligence of the manufacturing industry not only improves the accuracy of parts, but also provides correct design decision-making solutions, resulting in a qualitative improvement in technology.

In the development of the modern UAV industry, real-time monitoring and predictive maintenance in the airworthiness process have become an important part of continuous airworthiness management. Real-time monitoring and predictive maintenance methods are based on the status of the equipment rather than the traditional time, which can more effectively prevent failures, extend the life of the equipment and reduce maintenance costs.

Specifically, it is to use the STM32F103ZE microcontroller to preprocess the sensor data and receive the data of the IG-500N sensor through the USART2 interface. The processing of these data by machine learning models includes converting binary floating-point data into decimal format and formatting the data if necessary to prepare for subsequent data analysis and processing.

In the Labview platform, multiple sub-modules have been developed to perform complex data processing tasks. For example, the track deviation calculation sub-module uses three-dimensional spatial coordinates to calculate the deviation between the actual flight path of the drone and the predetermined route, and the application of artificial intelligence technology provides complex mathematical models and algorithm support.

Through the 3D drone model established by SolidWorks and combined with the obtained three-axis attitude angle information, the real-time attitude of the drone can be simulated in Labview. This function not only improves the interactivity and intuitiveness of the system, but also highlights the key application of artificial intelligence in the identification and prediction of flight patterns.

The system displays the flight status of the drone in real time through the graphical display of the module, such as three-dimensional trajectory, two-dimensional trajectory, real-time numerical display box, etc. This data visualization function enables operators to understand the state of the drone more intuitively, and also reflects the role of artificial intelligence in data processing and user experience optimization.

The application of artificial intelligence technology allows the system to automatically save and record all test data for preliminary flight performance analysis. This not only reduces the burden of manual data analysis, but also chooses to use machine learning algorithms for pattern recognition and trend prediction of flight data, which can improve the operational safety and efficiency of UAVs.

The introduction of AI has not only brought technical support to the technical level of airworthiness verification, but also brought considerable challenges to airworthiness management. At present, the application of artificial intelligence technology is commonly used as generative artificial intelligence technology. Generative artificial intelligence technology refers to the artificial intelligence technology in which computers learn and analyze from huge data sets based on certain algorithms, models and rules, so as to create new original content. For generative artificial intelligence technology, the state has issued the Interim Measures for the Management of Generative Artificial Intelligence Services (hereinafter referred to as the Interim Measures), which puts forward the requirements for the use of generative AI to comply with security credibility and comply with morality, ethics and public order and morals. Among them, the security credibility of AI is the judgment of AI's own ability and the judgment of human trust in the work of AI. The latter is the judgment of AI users and the code of conduct in the industry. In the process of referring to the airworthiness system of UAVs, artificial intelligence technology will correct the development direction and application scenarios under the supervision of this Interim Measures to ensure that the industry continues to be good.

In addition, it is mentioned in the "Smart Supervision" section of the "Roadmap for the Construction of Smart Civil Aviation" that in order to improve the supervision efficiency and quality of regulatory departments and realize the construction of "digital + government", it is necessary to further improve the integrated and innovative digital government, and build a data-driven industry supervision and integrated and innovative market operation monitoring system. The article shows the country's positive and encouraging attitude towards the application of AI to realize the intelligent process of the civil aviation industry, which shows the same optimistic prospect for the introduction of the policy of AI application in the airworthiness system of unmanned aerial vehicles.

5. Conclusion

This article provides a detailed analysis of the feasibility of applying artificial intelligence technology in the airworthiness system of unmanned aerial vehicles, and explores its role in maintaining and ensuring the airworthiness of unmanned aerial vehicles. Through literature review, comparative analysis, and case studies, this article first summarizes the current development status of unmanned aerial vehicle airworthiness systems and points out existing problems. Subsequently, the article conducted an in-depth analysis of the application cases of artificial intelligence technology in the traditional airworthiness field, examining the potential applications of related technologies. On this basis, the article summarizes the current development status of unmanned aerial vehicle airworthiness intelligence and comprehensively evaluates the feasibility of applying artificial intelligence technology in the unmanned aerial vehicle airworthiness system.

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