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RESEARCH AND DESIGN OF AMPHIBIOUS AIRCRAFT FIRE-EXTINGUISHING SIMULATION MANAGEMENT SYSTEM BASED ON DIS

Hanyue Shi[1], Hui Xie[2], Xin Hu[1], Yiming Liu[1], Zhiyong Cai[2], Hongjun Zhao[2] & Yaoming Zhou[1,3,*]

[1]School of Aeronautic Science and Engineering, Beihang University, Beijing, China
[2]AVIC General Huanan Aircraft Industry Co., Ltd., Zhuhai, China
[3]Beijing Advanced Discipline Center for Unmanned Aircraft System, Beihang University, Beijing, China
*Corresponding author, E-mail: zhouyaoming@buaa.edu.cn

Abstract

Forest fires are devastating to forest resources and ecosystems and large fire fighting aircraft is one of the most effective tools for forest fire fighting. Aiming at the gap between the use experience of large fire-fighting aircraft in China and the simulation of fire-fighting flight by water drop, this paper studied and designed a fire-fighting simulation management system for amphibious aircraft with high simulation performance and high real-time performance by using Windows operating system and Qt user graphical interface development framework. Firstly, the characteristics of the Distributed Interactive Simulation System(DIS) and the requirements of the aircraft fire extinguishing simulation management system were analyzed in this paper, and then a software development framework for the aircraft fire extinguishing simulation management system based on the Model-View-Control(MVC) and modular ideas was proposed. The system was divided into six modules to properly handle the relationship between task scheduling, data management, dynamic model invocation, and human-computer interaction, which not only realized the required functions of the system but also improved the stability of the system. Finally, the software of the aircraft fire extinguishing simulation management system was developed. After testing the software, the test results showed that the fire extinguishing flight simulation management system can meet the mission requirements and has high real-time performance and simulation effects.

Keywords: Distributed Interactive Simulation; amphibious aircraft; firefighting aircraft; simulation management system; flight simulation

1. Introduction

Forest is not only an important means of production, but also an important ecological resource.China's forest coverage rate exceeds 23% and is still in the stage of rapid development [1]. At the Climate Ambition Summit on December 12, 2020, General Secretary Xi Jinping solemnly announced that by 2030, China's forest stock will increase by 6 billion cubic meters from 2005, and it will make greater contributions to the global response to climate change. However, China is a country prone to forest fires. In 2020 alone, there were 1153 forest and grassland fires, including 7 major forest fires, and the affected forest area reached 8,500 hectares [1], especially in Liangshan, Sichuan Province on March 12, 2020. The major forest fires in the state, which caused 19 deaths and 3 injuries, were highly valued by the Party Central Committee and caused widespread concern throughout the country. The Southeast Forest Region, Southwest Forest Region and Northeast Forest Region are the most concentrated areas of China's forest fire prevention key areas [2]. They are also the areas with the largest number of fires and the largest area of damaged forests over the years [3-4]. The terrain there is mostly mountainous or hilly and road traffic conditions are poor. Once a forest fire occurs, large-scale ground firefighting equipment can hardly reach the vicinity of the fireground. It can only rely on manpower which is inefficient and high-risk to control the fire, and the large fire extinguishing aircraft was born to deal with this problem.

Fire extinguishing aircraft is a kind of civil aircraft that can drop water in the air to extinguish fires. When a fire occurs, the water carried by the aircraft is used to spray on the fire, the line of fire or the fire point, which can effectively curb the spread of the fire, and reduce the impact of fire on life, property and the environment [5]. Compared with traditional ground fire-fighting equipment, the biggest advantage of a fire-fighting aircraft is that it can quickly reach and approach the fire site from the air to carry out fire-fighting operations, which is extremely important to curb the spread and spread of the fire in the initial stage of the fire. The only large fire extinguishing aircraft in China is the amphibious aircraft "Jiaolong" AG600 developed by AVIC General Huanan Aircraft Industry Co., Ltd., as is shown in Figure 1. China's experience in using large fire extinguishing aircraft to perform water fire extinguishing tasks is still blank because the AG600 fire extinguishing model is in the acceptance stage. The use of real fire-fighting aircraft to train pilots to extinguish fires and draw water is not only expensive but also risky. Therefore, it is particularly urgent to build an amphibious aircraft fire-fighting simulation system.

Figure 1 – AG600-"Jiaolong"

2. Distributed Interactive Simulation

Flight simulation is a typical human-in-the-loop simulation. Nowadays, the widely used simulation system architectures are divided into High-Level Architecture(HLA) and Distributed Interactive Simulation [6-8].

HLA is an open and object-oriented architecture. It separates the application layer from the bottom layer by providing a universal and relatively independent Run-Tim Infrastructure(RTI), which is its most notable feature. It has the advantages of high scalability, high interoperability and interoperability, and high synchronization. It is especially suitable for large-scale interactive simulations that include different operating systems. DIS is an architecture that connect simulation equipment distributed in different places by computer network protocols to form a virtual synthetic environment that is coupled with each other in events and space [9]. The system based on the DIS architecture has the advantages of simple and reliable structure, high real-time performance, and high reproducibility. And it can meet the needs of flight simulation simulators. The amphibious aircraft firefighting flight simulator in this article is based on the DIS architecture.

From the perspective of the physical structure of the system, DIS can be seen as composed of simulation nodes and computer networks. The simulation node is responsible for realizing the simulation functions of this node, such as the calculation of aircraft dynamics model, visual image display, instrument panel simulation, etc. These simulation nodes are connected by computer network, and the object entities in the simulation nodes can interact with each other through data communication. The structure of the amphibious aircraft fire extinguishing flight simulator is shown as Figure 2. The various systems are connected to each other in the high-speed Ethernet using the User Datagram Protocol(UDP) as the communication protocol.

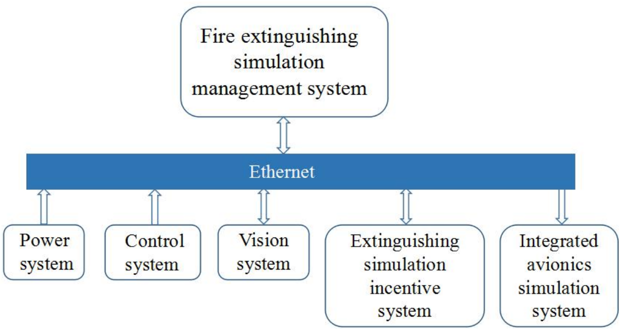

Figure 2 – The structure of the amphibious aircraft fire extinguishing flight simulator

FIRE-EXTINGUISHING SIMULATION MANAGEMENT SYSTEM

The fire extinguishing simulation management system is the nerve center of the fire extinguishing flight simulator. It converts the electric potential of the steering stick, pedals and throttle lever obtained from the control system and dynamics system ,and turn them into the rudder deflection angle and engine power. These parameters are calculated by the internal dynamics model of the system to generate flight status information such as the position, speed, acceleration, and attitude of the aircraft. Then the flight status information is transmitted to the visual system and the integrated avionics simulation system to simulate the external environment scene of the fire-fighting aircraft and the internal instrument panel display scene of the cockpit. The fire extinguishing simulation management system also accepts water drop or drawing mode commands, hatch opening and closing commands, and opening and closing commands of the water bucket from the fire extinguishing simulation excitation system, and feeds the corresponding signals to the fire extinguishing simulation excitation system and the visual system to complete the water drop and bail tasks in the amphibious aircraft firefighting flight simulation. It can be seen that the role of the fire extinguishing simulation management system is very important, and it needs to be properly designed to meet the functional needs of the flight simulation simulator.

3. Software Design of Fire Extinguishing Simulation Management System

3.1 Software Development Platform

The fire-fighting simulation management system mainly provides functions such as human-computer interaction, model solving, data management and task scheduling for the amphibious aircraft fire-fighting flight simulator. Based on the applicability of the software, this paper chose a high-performance electronic computer based on the X86 architecture as the development environment of the fire extinguishing simulation management system software. The operating system version is Microsoft's Windows 7 and the software is also compatible with Windows 8 and Windows 10. The fire extinguishing simulation management system software was developed by Qt graphics development tools. Qt is a cross-platform C++ user graphical interface application development framework. It provides a one-stop solution for application development. It has excellent cross-platform features, rich APIs and supports 2D/3D graphics rendering, making the development process become simple and efficient. The Qt version selected in this article is 5.9.9, the compiler version is MinGW 5.3.0 32bit, and the development language is C/C++.

3.2 Software Architecture Design of Fire Extinguishing Simulation Management System

According to the modular development concept, the fire extinguishing simulation management system software is divided into six functional modules, which are human-computer interaction module, data communication module, model solving module, data management module, real-time dispatching module and fire extinguishing evaluation module. The software architecture of the fire extinguishing simulation management system is designed by using Model View Controller(MVC) mode [10], as shown in Figure 3. The controller part in MVC is composed of real-time scheduling module and data communication and public data area management modules in the software; the view part in MVC is composed of human-computer interaction modules for monitoring the software running status, displaying information and setting; The model part of MVC is composed of model solving module and fire extinguishing effect evaluation module.

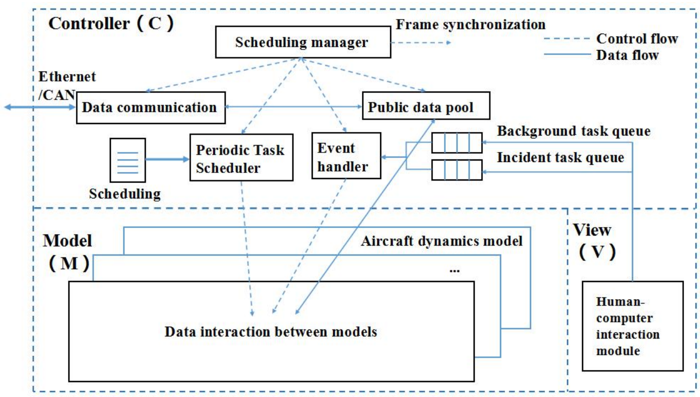

Figure 3 – Schematic of software mode of fire extinguishing simulation management system

The software architecture designed based on the MVC model is shown in Figure 4. The software operator set the simulation initial conditions, control the simulation process, check the software running status, and view the simulation results by human-computer interaction module. Run control instructions are executed through the real-time scheduling module. After the simulation starts, the data management module obtains the operation quantities of each step of the fire-fighting flight simulator pilot through the data communication module, and transmits them to the model solving module. The model solving module solves the operation quantities under the control of the real-time scheduling module. It calculates the flight status parameters of the aircraft, and then generates a data file through the data management module to save these flight status parameters in a local folder. Meanwhile, the flight status parameters will also be displayed to the software operator through the human-computer interaction module, and some flight status parameters will also be transmitted to other systems through the data communication module. The fire extinguishing evaluation module reads the simulation data in the local folder to quantitatively evaluate the effect of the fire extinguishing simulation flight, and displays the evaluation results to the software operator through the human-computer interaction module.

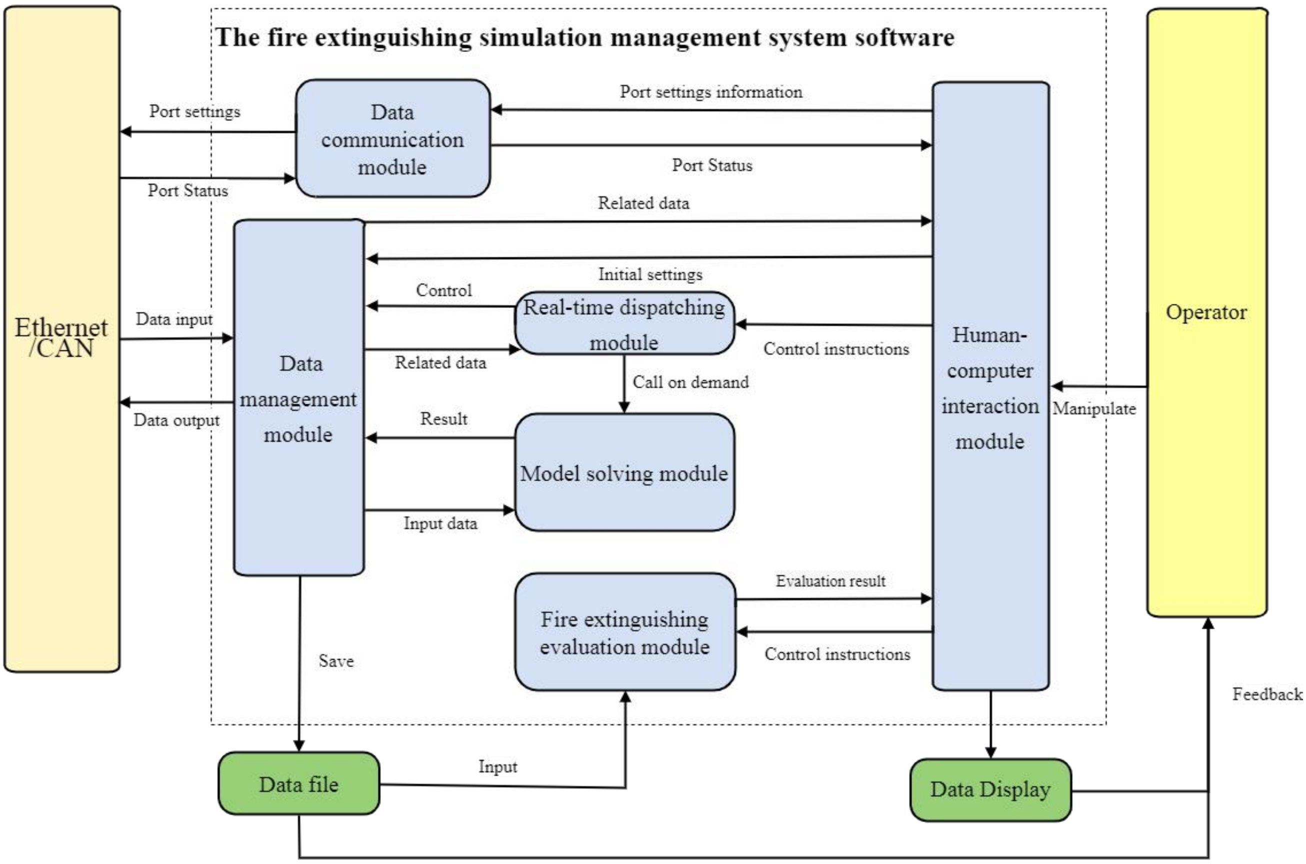

Figure 4 – Software architecture

The software operator generates occasional tasks and background tasks through the human-computer interaction module, and the scheduling manager determines the task execution order according to the priority of the tasks, and then calls different models to execute the tasks. When each model executes tasks, it obtains input data from the public data area, and outputs the calculation results to the public data area for storage, so that it can be called by other models or transmitted to other systems through the communication port. The dispatch controller also controls the data communication and software operating frequency. The detailed design of each module is described below.

3.3 Software Detailed Design

In the software architecture design, the software is divided into six modules. And each module has its own design logic and function. The detailed design is as follows.

3.3.1 Human-computer Interaction Module

The operator of the fire extinguishing simulation management system software interacts with the software through the human-computer interaction module, and realizes the communication interface settings and status viewing, simulation initial conditions setting, simulation operation control, flight status and control parameters viewing, and fire extinguishing effect evaluation results viewing operations through the Push Buttons, Combo Boxs, Line Edits, Widgets and other components on the software user graphical interface. The simulation initial condition setting includes setting the mission type, the initial state parameters of the aircraft, the simulation mission environment, and the initial position of the aircraft. The operator can also to view the corresponding relationship curve between the main flight parameters and time in the process of flying, drawing water, dropping water, taking off and landing, and observe the dynamic change process of those parameters through this module. The software interface layout is detailed in Chapter 4.

3.3.2 Data Communication Module

The software uses the UDP/IP protocol to exchange data with other systems, and its work process is shown in Figure 5. The encoding format, data sequence, data type, data meaning, and port number are agreed with other systems, and then the data is encoded and sent according to the agreement, and the data packets sent by other systems are also accepted and decoded according to the agreement. In this article, the data is encoded in the format of "packet header" + "packet body". The packet header format is 4 32-bit integer numbers, which are data identifier, sender identifier, receiver identifier, and packet body length in sequence.

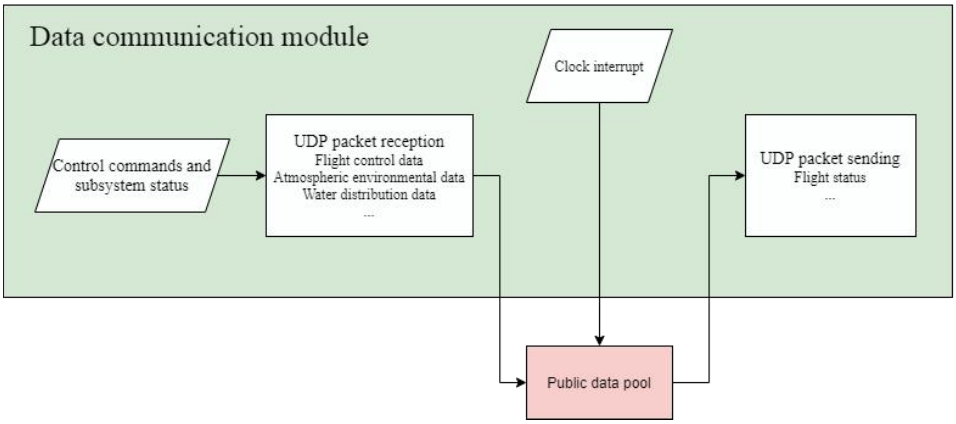

Figure 5 – Work flow of data communication module

3.3.3 Real-time Scheduling Module

The real-time scheduling module divides dynamic model calculation, data storage, data display, etc. into multiple different threads, so that they can be calculated in parallel with each other to ensure real-time simulation. After comprehensively considering the continuity of the visual image, computer performance, Ethernet delay and bandwidth, the simulation model calculation cycle is set to 20ms, but the actual model solution time is lower than 10ms, and there is still potential for upgrading. The real-time scheduling module also has the responsibility of synchronizing the internal clock signal of the software to ensure the consistency of time. For periodic messages and occasional messages generated by periodic simulation tasks and occasional tasks within the software, the module needs to ensure that these messages are submitted in time before the next cycle of simulation model calculations.

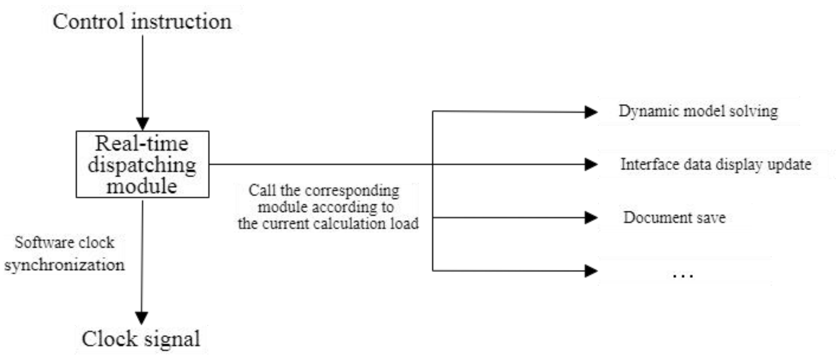

Figure 6 – Working diagram of real-time scheduling module

3.3.4 Data Management Module

The data management module is responsible for the reception, distribution, recording and storage of data, whose working diagram is shown in Figure 7. The data management module mainly controls the local data and global data inside the software: the data management module stores the acquired data in the public data area for sharing. In order to ensure the security and integrity of the public data area, the module adopts a design strategy that uses the shared data area management technology to control the data interaction between simulation models, which can effectively eliminate the access conflicts of different simulation models to the same data object.

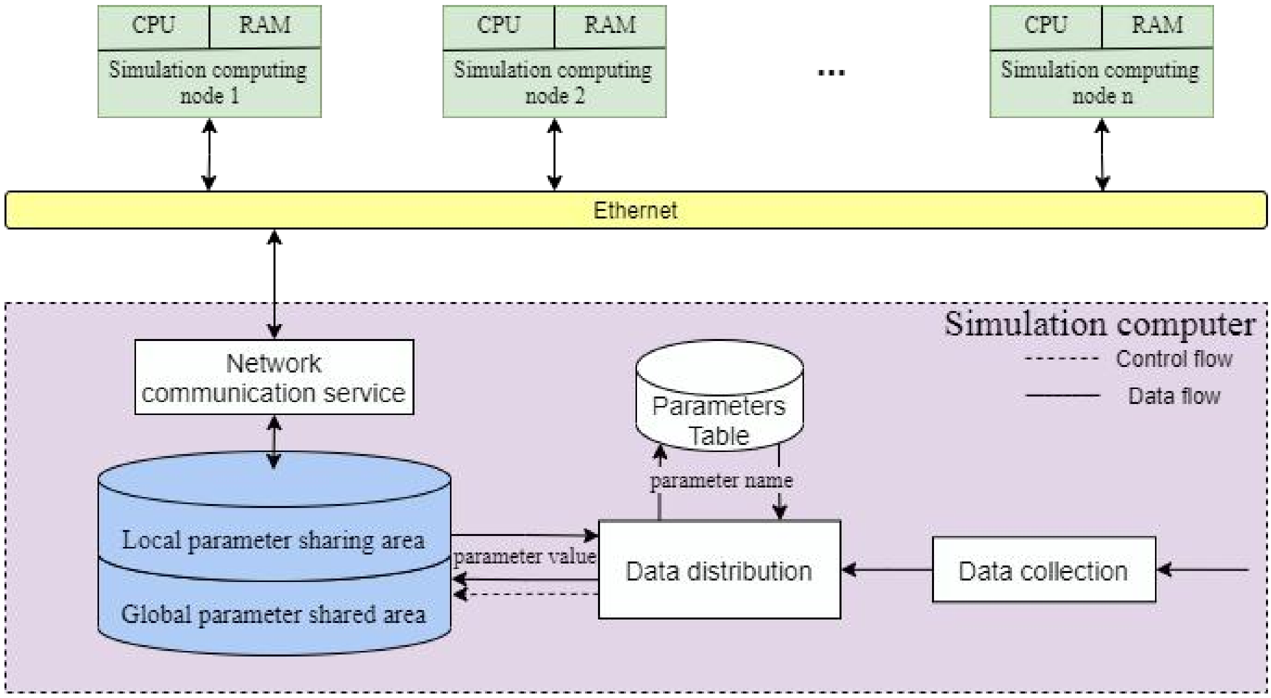

Figure 7 – Working diagram of data management module

3.3.5 Model Solving Module

The entire flight process of the firefighting aircraft is divided into 4 stages according to the initial state and mission type, namely, water drop, land on the water, water drawing on the water and take off on the water [11], as shown in Figure 8.

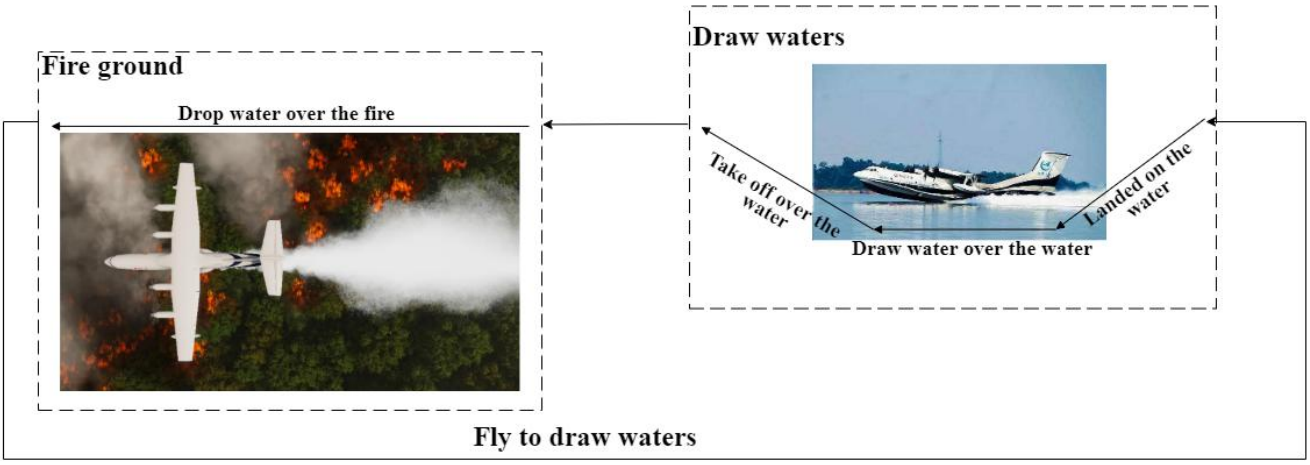

Figure 8 – The whole process of extinguishing the plane flight

For these 4 stages, the model solution module sets up 2 dynamic models to solve the problem. The initial state and work content of the aircraft at each stage is shown in Table 1. The stage of the water drop are solved by the dynamic model of the water drop [12-13], and the stage of water drop, water drawing and the water taking off are taken by the dynamic model of the water drawing. The connection between the 4 stages is controlled and switched by the flight simulation software. In different stages of the simulation process, different dynamic models are called for calculation.

Table 1 – The initial state and work content of the aircraft at each stage

Stage	Initial state	Work content
water drop	in flight	simulate the process of aerial water drop
land on the water	in flight	simulate the process of landing from the air to the water surface
water drawing	in flight	simulate the process of drawing water from the water surface
take off on the water	at anchor	simulate the process of taking off from water surface

The dynamics model is constructed by the aircraft's six-degree-of-freedom control equation combined with aerodynamics and hydrodynamics. The potential signal obtained from the steering rod, pedals and other control components is converted into the rudder deflection angle to calculate its aerodynamics. The generated forces and moments are then integrated twice to calculate the displacement and attitude of the aircraft.

3.3.6 Fire Extinguishing Evaluation Module

In the fire extinguishing flight simulation, the fire extinguishing aircraft flies to the fire site after injecting on the ground or drawing water. After reaching the fire site, the aviator selects a certain water drop strategy, presses the drop command button, and sprinkles water to the fire site at one time or in batches, and then returns to operate the water drawing mission again. The process is shown in Figure 9. After the water is poured, the visual system will transmit the fire location and water distribution information to the fire extinguishing simulation management system software through the UDP port. The software will save the data to the local folder after receiving the fire site and water distribution data. And the fire extinguishing evaluation module will read the data, quantitatively evaluate the fire fighting effect, and then display the calculation results on the software user graphical interface [14].

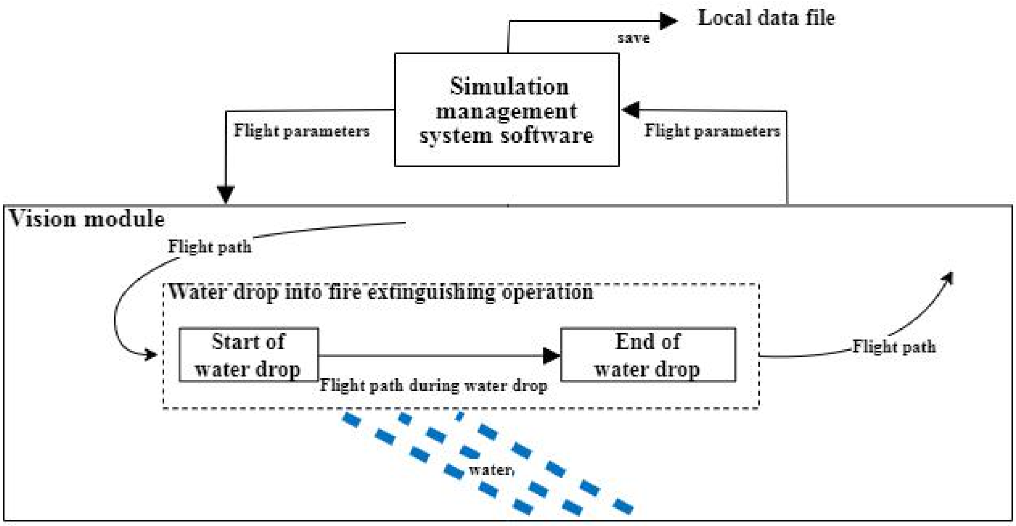

Figure 9 – Schematic diagram of water drop process

4. Fire Extinguishing Simulation Management System Test

This article uses the AG600 semi-physical simulation environment built by AVIC General Huanan Aircraft Industry Co., Ltd. as the application environment of the simulation management system. The fire extinguishing simulation management system software is installed on the simulation control computer, which is a high-performance electronic computer with Microsoft Windows 7 64-bit operating system. After the software installed, start the software, and the software interface is shown in Figure 10.

Figure 10 – Software interface of fire extinguishing simulation management system

According to the software work flow in Figure 11, firstly click the initial setting button in the label 1 area in Figure 10 to set the initial simulation conditions. The task type and working conditions, and the initial setting of the aircraft Position, posture and speed, mission location and angle of view can be set in the label 1 area in Figure 10. Click the initialization button in the label 3 area in Figure 10 to initialize the system, and then click the start button below the initialization button to start the simulation. At this time, the software will continuously obtain the potential data of the driving stick and the throttle stick. After the collected data is solved by the dynamic model, the position, attitude and other flight status data are transmitted to the visual system for display. The software will also give corresponding feedback based on the pilot's water drop/drawing operation, and perform the drop/drawing operation. After the drop is finished, the water throwing effect evaluation button in the label 1 area in Figure 10 can be clicked to view the fire field and water distribution data and calculation data for quantitative evaluation of water throwing efficiency. The simulation effect of the human-in-the-loop fire extinguishing flight simulation system is shown in Figure 12.

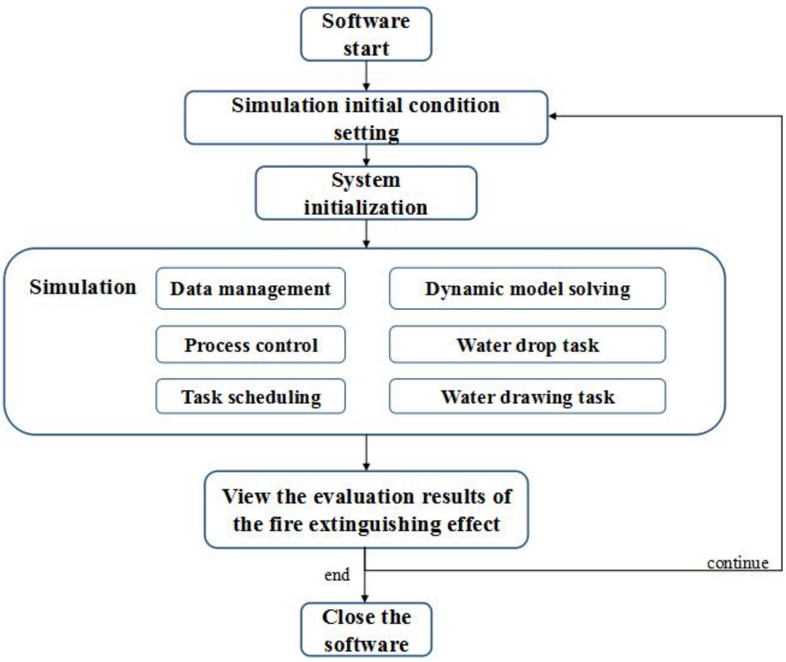

Figure 11 – Work flow of fire extinguishing simulation management system software

Figure 12 – Simulation effect of human-in-the-loop semi-physical fire extinguishing flight simulation system

5. Conclusion

Aiming at the blank of domestic large-scale fire-fighting aircraft's water extinguishing flight simulation, based on the Windows operating system and Qt user graphical interface development framework, this paper researched and designed a set of amphibious aircraft fire-fighting simulation management system which has the characteristics of high simulation, high real-time and high stability, and developed its software to realize the amphibious fire-fighting aircraft whole-process flight simulation including water drop and water drawing. It has been verified by experiments and able to meet the needs of the mission.

The fire-fighting simulation management system designed and developed in this paper can also be applied to pilot flight training, life-saving simulation experiments and other tasks for flight designers to carry out verification of related systems.

This article is just a preliminary research and design of the fire extinguishing simulation management system. The simulation frequency and functions of the fire extinguishing simulation management system still have room for improvement. In the future, it can be considered to increase the simulation frequency to more than 100 Hz to obtain better visual display effects. Functions such as simulation result reproduction, ground take-off or landing can also be considered to add.

6. Acknowledgement

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7. Copyright Statement

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