Design of UAV Flight Simulation Software Based on Simulation Training Method

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Abstract: -UAV (unmanned aerial vehicle) has been widely used in both military and civilian fields in recent years. With the development of UAV, high quality training for the UAV operators on the ground is necessary and urgent, the fidelity of simulation training system is very important, the fidelity training system can simulate the flying environment on the sky, the flying simulation software is the core of the training simulator system, the fidelity and accuracy of software can ensure of the reliability and efficiency of flying simulation system. The study of structure, composing and function of the UAV system is the premise; in the paper, the flying simulation software is proposed based on object oriented according to the actual training of UAV. The research is necessary in the development of UAV training simulator system.

Key-Words: - UAV (Unmanned aerial vehicle); Simulation training; Flying simulation software; Object oriented; Dynamic simulation

1 Introduction

UAV (Unmanned Aerial Vehicles) is an unmanned aircraft which can be repeatedly used [1]. As known that flight training system has many advantages such as energy conservation, economy, and security without limitation of field and weather, etc. the system also can shorten the training periods and improve the training efficiency. Most importantly that, the training system can simulate some risky and hard to deal tasks [2]. The UAV has comprehensive been applied in the manifold military actions. We can adopt the training system instead of the real equipment in the actual training excise; the training effects are directly determined by the reality of the flight simulation system.

Simulation software is the most important part of the flight simulation training system. Flight simulation software is composed of mathematical modeling and related programs, e.g., flight dynamics modeling, equivalent flight control software (modeling of flight control computer), modeling of navigation system, establishment and programs of data base.

In the paper, we analyze the structure and functional characteristics of UAV system. The flight simulation software which adapts the fidelity training is also researched. The explorations of the flight simulation software have important theoretic and practical values.

2 Key Technology of Flight Training System

Flight simulations and related mathematics modeling technology have been applied in design processes, investigation and practical use of the training system. The flight simulation system can be regarded as the tool which can reduce the flight hour, training cost and improve the safety of flight. The flight training technology is the basic technique of the flight training simulator. The flight training simulation system is developed simultaneously with the development of mathematical modeling and flight simulation. As the hardware is in the loop simulation system, flight simulation system is a typical manned loop simulation system. The flight training simulator includes dynamic modeling, kinematics modeling, environment modeling and some subsystem modeling, all of which is calculated on the simulation computers [3,4].

The modeling of UAV aircraft system is the core of the simulation system. A typical training system includes the dynamic model, subsystem of aircraft model (such as engine modeling, flying control modeling, navigation modeling, apparatus modeling), and integrative environment modeling (such as the static atmosphere, the disturb atmosphere). The model's accuracy will determine the fidelity of the simulator. As for extensive

aeronautic equipment, flying simulation training system should have a suit of validate and evaluation system. So flying simulation system of the aircraft has been getting more and more attention in navigation field and the requirement of it is largely increased.

2.1 Research of Flight Simulator

The research of training simulator is getting more and more maturity at present, moreover the large scale industry has been formed. The companies who produce the training simulator involve CAE company of Canada, THALES company of England, the Frasca company of the USA, FCS company of France. The technology in these companies can afford us the related reference. As the flight simulator needs high concentrated technologies, so many academy and graduate school do a lot of research work on it. These organizations include Delft university of Holland, SiMoNa graduate school, NLR laboratory and Toronto university of Canada, they can provide us the support in technique of basic research [5].

2.2 Development Direction of UAV Simulator

Department of defense (DOD) of the US issues new route of the UAV department—"Unmanned Aircraft System roadmap 2005~203"[6], which presents the recent researching information on the UAV system of the USA, e.g., the requirement and development trend of the UAV. The control platform technology in new roadmap points out that the ground control car will be instead of the joystick system and the headpiece which is used by the UAV ground operator. The operator who puts on the headpiece could see the sense in any directions. Roadmap refers that the ground station can only do the flying task and could not do the training work now, which will bring high cost on training, on the other hand in using and maintenance aspect, roadmap points that high fidelity training simulator should have the same functions as the real equipment to the operators. So the fidelity training simulator could reduce the use times of real aircraft. The UAV ground station can be looked as a part of the training equipment, which can reduce the cost of exploration and maintenance on independence training system. As the function of UAV training system , the flight hours for the UAV real equipment will be reduced, so it also can decrease the service hours and cost of aircraft [7].

3. Design of Flight Simulation Software

The Flight training simulator is a complicated simulation system, which includes the mass of mathematical models, so it is a hard work to establish the flight simulation system. The Flight simulation software design of the project is the purpose of operator's training, so the simulation model should reflect the essence of system, and the system should take the aircraft dynamic character into consideration, completeness of the whole system also is very important.

As we known that the flight simulation model could not be completed in one step; the research course is a sequential process, which needs the module can be reconfigured and changed. In the modeling process, we can adopt module and hierarchical methods, and establish a universal modeling which has common characteristics for all modeling and can be applied by each model. In this way, it can achieve the designed aim for the complex problem and large system.

3.1 Technology of Object Oriented

Object oriented (OO) technology is a popular technology in researching and designing courses for the complicated software, with its comprehensive and embedded application, the technique is developing very fast. The modeling technology of object oriented applies tradition thinking mode to analyze the complex system in modularization method. It can identify the essence of the question and pick up the relationships between the modules. Then it sets up an accurate and comprehensible model for problems

Object oriented modeling technique integrates the objects and their relationship in one concourse, which includes static characteristic rule and dynamic action. It applies the same running laws and action rules to realize dynamic changes. The functions of training system are realized through the cooperation of different object models. Object oriented technology and the application framework technology provide us an effective tool to deal with the large and complex system. The important contents of the object oriented modeling are analyzing specialty of complicated problems, picking up the static characteristics and dynamic behaviors of the object model. After the works above is finished, the simulation models about the complicated system can be set up, which have the uniform framework. Object oriented simulation is based on object oriented technique, it adopts object oriented modeling method, which considers the world is consist of different objects and have relationships between each other. The technology adopts the custom thinking mode and have the

characteristic of abstraction, inheritance, aggregation, polymorphism, etc.[8,9].

Flight simulation software is the most important part of the UAV simulation system. The designing process is as follows, from the physics system for conception modeling and then simulation modeling, firstly, we can analyze the physics system, and then finish modeling work of the system; finally, we debug the program of simulation software. This modeling course is a circular process. The most important part is to establish a high efficiency, expansibility, opening and maintainability flight simulation system, the uniform framework could do help to maintain and expand the system in the future.

3.2 Design of UAV Simulation Training System

Design of simulation system is based on correct and logical research work of the researched system. The system should be described clearly, then identify, abstract, organize and show the relationship between modules of the system, and grasp the basic component and correlations in the system. Finally we could establish the simulation model with hierarchy framework. In the paper, we research the structure of aircraft system and the control system of a certain kind of UAV. From whole to part route in the modeling is adopted which is according to principles of object oriented. We construct the real time dynamic flight simulation model and the flight control system model (flying control computer model), and then we form up the operational framework of the system model. The uniform operation framework can not only enhance the modeling flexibility but also realize the stabilization and high operational efficiency of the simulation model.

3.2.1 Structure of UAV System

UAV system includes two main parts, airplane system and ground control station. In the paper, the designed simulation system of UAV mainly involves UAV dynamic combination model and flight control computer model; the ground station adopts the station of real equipment. The framework of UAV simulation system is shown as Fig.1. The UAV airplane system adopts flight simulation system, the UAV simulation system can be divided into two parts, one is the flying control software, and another is a dynamic simulation model, which are shown in Fig.1, the mainly functions of flight control software is that telecontrol command decode, remote sensing code, calculate of flight control law ,etc. The UAV is carrying out work in the air who communicate with ground station by radio system, but in the training system the flight simulation system (which instead of the real UAV) is communicating by RS-232 (the ground station affords standard port of RS-232 for convenient measurement working).

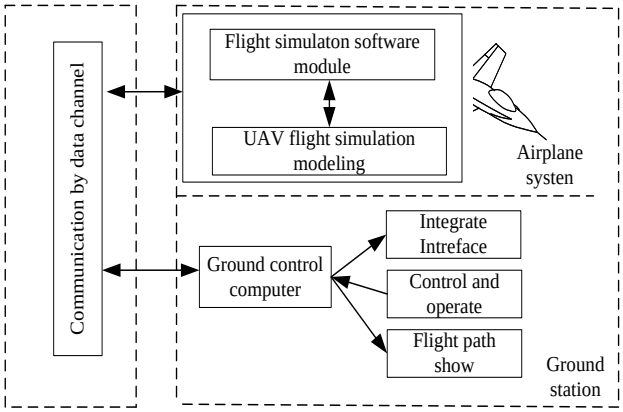

Fig.1 Structure of UAV system

The UAV flight simulator system is a complicated system, which is composed of many complicated subsystems; these subsystems have relationships between each other. According to the different functions, we can divide the subsystem into subsection. The simulation system is used for fidelity training of UAV operators. So we should do the research work of dynamic model and kinematics model in detail. The Engine system is taken as a whole system, in other words, engine model is only concerned with input and output characteristics of the engine.

The UAV flight simulation system can be divided into some parts based on physics structure and function module. Each module such as engine module, dynamic module, and kinematics module, etc. has its own attributes and functions, we pick up the intramural characteristics and external relationships between each part, encapsulation attributes and behaviors based on the frame. The instance of the class represent model of substantiality object.

Flight simulation system indicates that the object oriented technology have much advantages in modeling on training simulator system. UAV simulation system can divide and encapsulation different class according to each module's functions and their relationships. Different class object have different attributes and actions, but the different object adopt the same input and output port to communicate because the port class is public, this character leads to the inside independence and outside unification of object oriented model. Through precise analysis of flying simulation

system, and characteristics and functions descriptions of different parts, we can find the system have the characteristics of hiberarchy, particularity and profundity. It can be regarded as extend model library or evolutive simulation model.

3.2.2 Structure design of UAV simulation system

The hiberarchy of the UAV simulation system is shown as Fig.2, Aircraft system can be divided into three layers based on function and parts grade. The hiberarchy framework of system includes three layers, i.e., simulation system layer, subsystem function module layer and function module layer.

In the simulation system, the objects on top layer have more responsibilities. The top layer's objects organize and manage the low layer's objects. The objects on low layer have more functionality. The simulation system includes flight environment model, airplane system model and task equipment model, etc. The airplane system model is the core of the system; it is made up of flying control computer model, engine model, kinematics model, sensor model, and data channel model and so on. Each part is formed one class which has their own characteristics. Every subsystem can be mapped one instance of the object; the instance can reflect their essence.

The first layer is the object of UAV flight simulation system. It is the uniform operation framework of the UAV system. It is mainly composed of flight environment model, airplane system model and task equipment model. The first layer takes charge of the organization, manoeuvre and management of whole system. e.g., the instantiation of object, method employ and operation management; UAV system is the action platform. So it can communicate with other object which is in the same layer.

The second layer is the function module layer of subsystem. The flight simulation system is the manager who take charge of the object in organization, management and the port for communications; the whole simulation object consist of every components, and the assembly process is flexibility, in other words the process is designed according to simulation purpose and configuration of a special UAV system. So the complexity of each object's combination is different. Then the object model can achieve the simulation of operation under given condition with specify air environment and task equipments of the airplane.

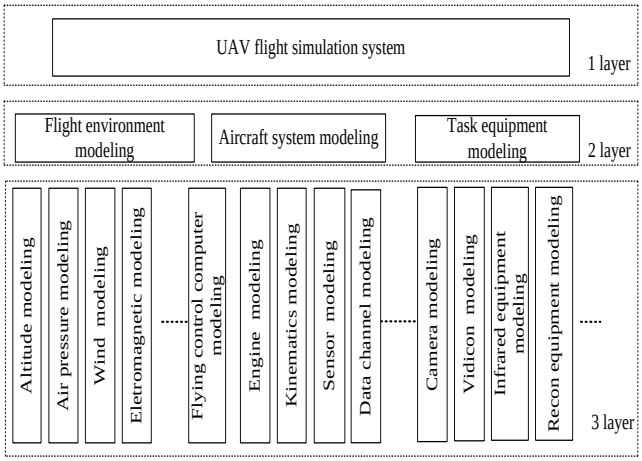

Fig.2 Structure and layer of UAV simulation system

The third layer is subsystem of the flight simulation model object. The airplane model is the core of whole simulation system. The subsystem of flight control computer model can offer output port for other model. The function of flight control computer model mainly includes telecontrol decode, remote sensing code and flight control law compute, etc. Each subsystem model has the independent function. In one subsystem, there are different submodels; these submodels can realize the subsystem's function through interactional operations.

3.2.3 Framework and Operation Mechanism of Flight Simulation System

Flight simulation system includes real aircraft system model and task equipment model. These models need run in the environment of real time, so the simulation model is called real time simulation model. Real time model is the important part of system; performances of the simulation system are determined by it. So we should pay attention on two parts, one is the structural design of class libraries, the rationalization of class structure in the system is very important to its repeat and extensive using; the other is the operating mechanism, which can organize and manage the whole simulation system run in real time and keep high efficiency [10-15].

(i) Hierarchy of the real time simulation system

The program design of system adopts a modular and hierarchy method. We apply the encapsulation characteristic of computer language C++ to set up class for function modular. The

variable and function should be protected is regarded as inner variable and function, the input and output function are regarded as public functions, through which it can communicate with other classes. Various classes in the language VC++ are shown as Fig.3, the CFlyDynFunc class, which includes 6 degrees of freedom dynamic operation equations of the UAV. Another class could get the UAV state parameters and flight posture parameters for the port function, the input and output function of the class is GetUAVState, this module is one of the core parts of the flight simulation system.

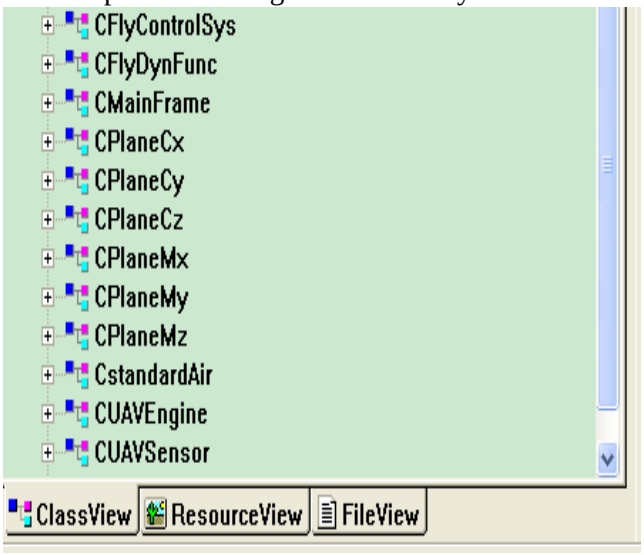

Fig. 3 Model class of UAV simulation system

In the Engine module class (CUAVEngine), it establishes a whole function model for the engine, the input parameters are the airspeed, altitude and instructions for the engine, etc., it can do the numerical operation work on the system state of big horsepower, middle horsepower and small horsepower. Then we can get the propulsion in certain airspeed.

In the dynamic coefficient module there has 6 classes, drag coefficient class (CplaneCx), lift coefficient class (CPlaneCy), side force coefficient class (CPlaneCz), roll moment coefficient class (CPlaneMx), yaw moment coefficient class (CPlaneMy) and pitch moment coefficient class (CPlaneMz). The task of the module is to calculate the aerodynamic coefficients. For example, in the class of drag coefficient (CplaneCx), the public function Set-State is the port function, through calculation of the given condition of height, speed and rudder deflection, we can get the drag coefficient. Other class using the port function of GetCx could get dragged coefficient Cx.

In the mass and the inertia moment class (CUAVMandI), the class affords mass and moment of inertia of the plane to the dynamic equation module, the module uses port function about GetMandI().

In the standard atmosphere module class (CstandardAir), the input parameter of this module is the height of the airplane and the output parameter is the atmospheric density. The output parameters which can be used in the calculation of aerodynamic moment and aerodynamic moment coefficients.

The design work of the flight simulation software system involves mathematics modeling and program. The mathematical model of the flight simulation is quite complicated. It could heighten efficiency and maintainability of the program when we adopt the object oriented method. The module's reasonable compartment is the basic work of the program. The whole simulation software adopts modularization, hierarchy method, it can use different method e.g., function blocking or hierarchy to divide the system module in a different hierarchy of the class.

Simulation program also could run in two modes: real-time mode and script mode. The real-time mode mainly used in real-time system and the script mode often used in the test process. The project adopts real-time mode, the cUAVModel of the class object for UAV real time simulation models would establish when every model object have been established. cUAVModel is running Run(RunMode Mode,double TimeStep) by itself, the object employs the static function which is Iterate(RunMode mode, double TimeStep) to run the simulation work. Iterate is running an ergodic course which is shown as Figure.4. This course could accomplish initialize job of every high-class, the low-class initialize job is done by high-class employ their function of Run (RunMode Mode,double TimeStep) to achieve.

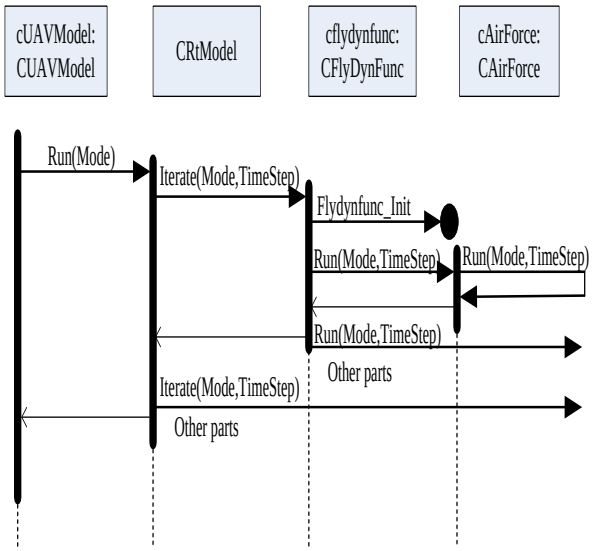

Fig.4 UAV simulation system initialization sequence diagram

After initializing working, the Iterate (RunMode mode, double TimeStep) function is running in real-time mode, each sub-model of the simulation system is accomplished information communication by employing holistic pointer. The MainFrame function is a threshold function of the system, it manages the running course of the system. When the class object of the MainFrame is constructed, it is doing the circular course of initialize, running and finish. Which is shown as Fig.5

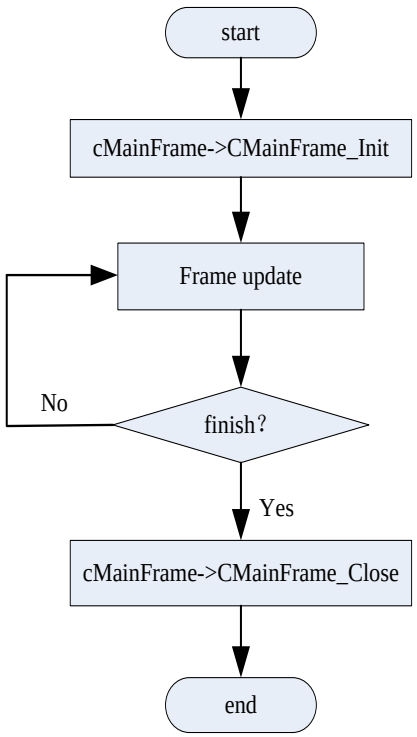

Fig.5 Flowchart of MainFrame function

(ii)Operation mechanism of UAV real time simulation model

There are a lot of simulation models in real time simulation system of UAV. Each model consists of different classes, and different class may have different structures. How to achieve model instantiation and make them operate in order is the key of real flight simulation.

CUAVModel (the UAV simulation system class) is a highly abstract concept. It is an abstract class through analyzing the common behavior and operation define from every submodel, there is not a concrete example for this abstract class (CUAVModel). This abstract class offers the common data structure and public operation to its subclass, in the submodel of different levels, the operation is realized according to their own demands. It allows its derived class to apply to multistate. Typical protection virtual functions include Initialize double, Input double, process double, output double. The main body for each simulation model are composed of them, which present the characteristic of every simulation model, the virtual function Run (RunMode Mode, double TimeStep) of the system is the port function to each simulation model. The operation frameworks for each simulation model are involved in their derived classes. According to different model, operating working for each derive class object such as initialization, input data, program work, output data and destroy function are performed [16-22].

In general, the derive class is constructed from the initialization of its basic class. In the process of class instantiation from different grade, the initialization of CUAVModel is achieved by the reconfiguring of construction function. As the whole class take charge of input and output functions of each subsystem model. It needs to accomplish updating of the input variable before the operation of system, so it needed to apply the standard construct function CUAVModel to register the input address of the model. The CUAVModel afford link operation such as Push Into Linked List (CUAVModel*) to assign memory for each class, every unitary simulation model class is a node of the link list, which maintain the static data member together. The head pointer is m_p Root and the foot pointer is m_pTail, every class of the simulation

model can be linked by the pointer m_pNext. The link structure of the simulation system is shown as Fig.4.

Part class consists of the simulation model of the system is packaged in whole class. Part class object as a member of the whole class should complete instantiation work when constructing the whole class object. Part class object applies the CUAVModel to carry out basic class initialization. When the whole and part class instantiation from CUAVModel have been accomplished, each simulation model could link together, and then the simulation can run in circular style and recursion arithmetic mode [23].

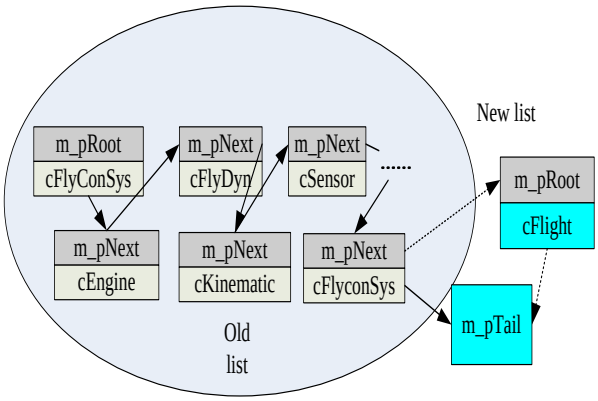

Fig.6 Chain structure of class object in simulation system

CUAVModel afford uniform framework for each simulation model. The derived class is encapsulated independence according to uniform framework, different derived class communicate with each other through interface port, which leads to high cohesion and low coupling of subsystems. CUAVModel registers each model's address by link list, the technique not only can manage simulation model effectively but also enhance simulation flexibility of the system. The new model could easily add to the link list and work in the same manner such as organizing, transferring and operating.

3.3 Simulation and Analysis

There are two parts in the simulation software, i.e., control and management module and master control computer module. Control and manage module takes charge of intercourse between operators and UAV simulation model, we can achieve the control task through the related interface; UAV simulation model is running on the master control computer, it is the core part of the whole system, we can entry the interface of the UAV simulation training system after starting up master computer, it could do different operation according to different instruction. The interface could achieve the functions as below:

(i)UAV simulation system initialization setting includes the airplane location, initialization, airplane initialization attitude, airplane task equipment on and off, takeoff parameters of the airplane.

(ii)Flight operation course, which offers the function of pause, continue, finish, etc.

(iii)Navigation and electronic map sets and display.

(iiii) Flight training evaluation and marking.

We can select different type of UAV before simulation flight. Before selecting the UAV, each button is forbidden to use except exit button just as shown in the Fig.5. The primary tasks of the simulation computer are the communication between operator and interface, setting and management of the system and running and calculating of the flight simulation model. The flow chart of the program is shown in Fig.7.

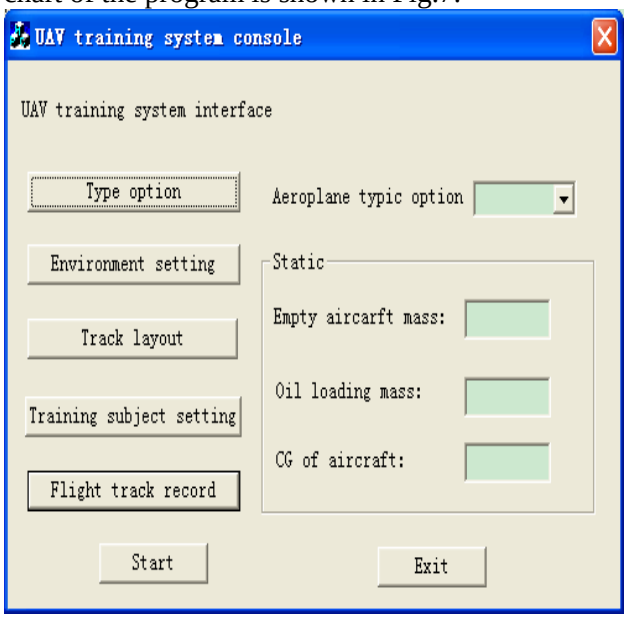

Fig.7 UAV training system console interface

Flight simulation software is developed with the computer language of Visual C++. The purpose of the simulation system is used for training of the ground operators. The flying simulation software based on the PC could communicate with ground station in real time and can receive the control

command and send the remote sensing information in related format. The flying simulation software could regard as UAV on the ground, the researching of the project adopts rocket roll booster. So we can set initialization values and do the simulation working based on initialization conditions.

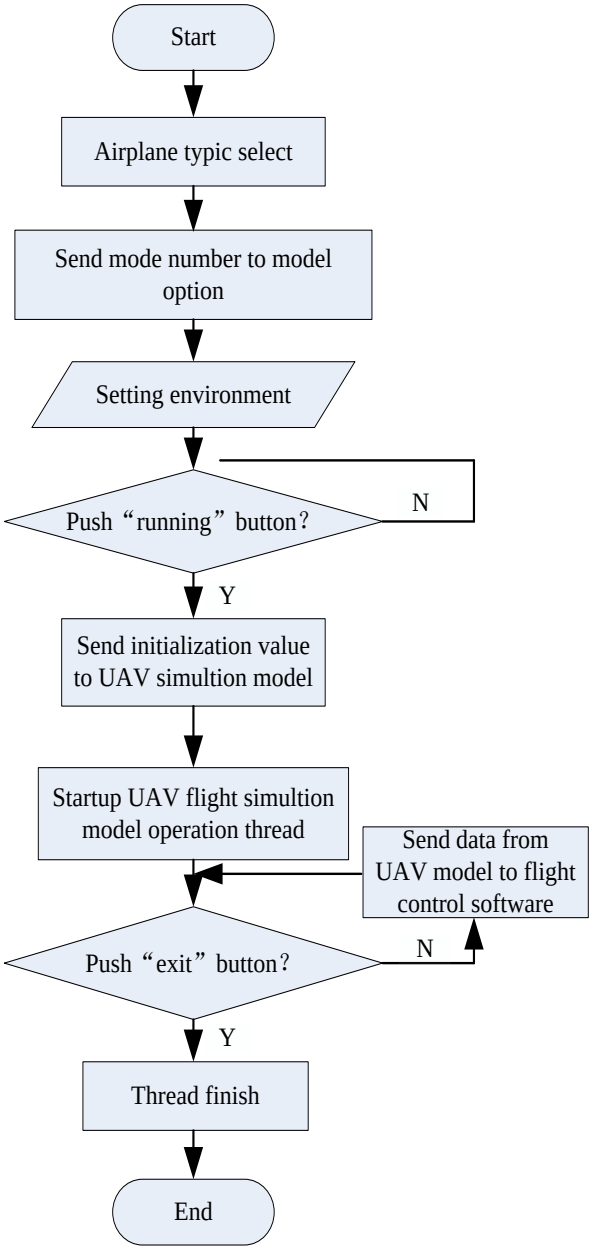

Fig.8 Flow chart of the simulation computer

We set the simulation time is 90sec, the initial speed of the UAV is 23m/s, initial pitch angle is 0 degrees and the steady speed is 25m/s, the steady value of pitch angle is 1.7 degrees. In the Fig.9, the speed curve recorded is presented; pitch angle curve is also presented in Fig.10. In the simulation, disturbs of wind are taken into consideration, in other words, the random vector Wind[x y z] in the control loop is added. In the Fig.9,10, parameter Wind[x y z]=[0 0 0]m/s is added，in the Fig.11,12, parameter Wind[x y z]=[X X X] m/s is added，adding wind vector as disturbing in the simulation, could afford comparatively actual environment for ground operators.

From curves of the simulation with typical parameters, we can find that there exist instability phenomena in UAV (e.g., shake frequency of typical parameters is increased) in the environment of wind, which is very close to actual situations. From simulation results we can see that the simulation software could satisfy the purpose of system, and the stability of the system is good.

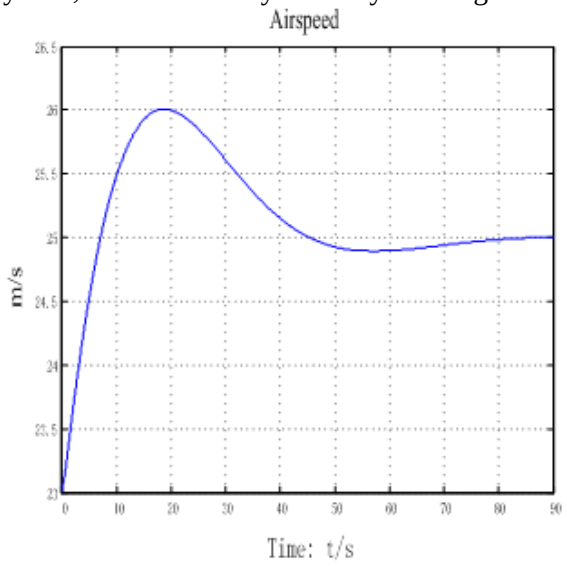

Fig.9 Speed graph in the simulation

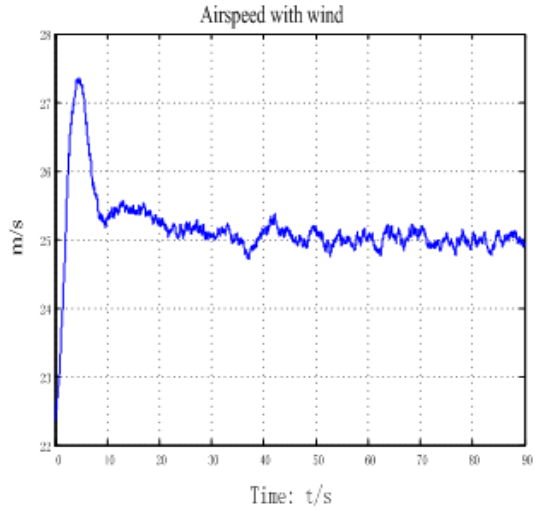

Fig.10 Speed graph with the wind in simulation

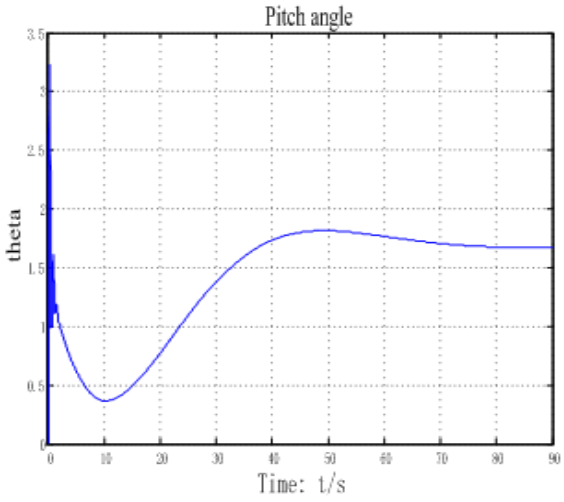

Fig.11 Pitch angle simulation graph

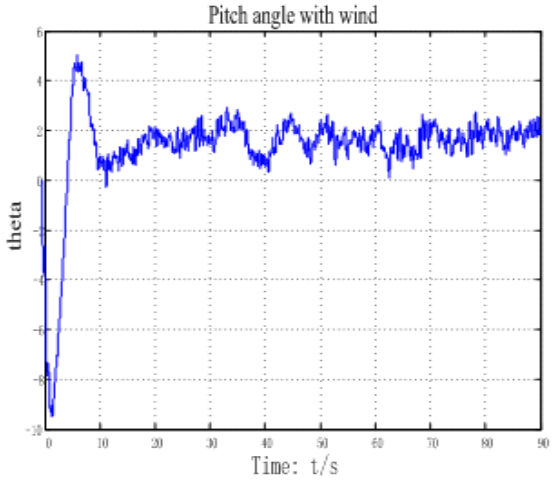

Fig.12 Pitch angle simulation graph with the wind

4.Conclusion

Flight simulation software is the core of the UAV training system. In the paper, we introduce the object oriented technique and its application in the flight simulation system. Comparing with the traditional technique of course oriented programme, object oriented technique can improve flexibility and maintenance of the program, also make the program is convenient to analyze, comprehend and design. We put forward 3 layers frame structure in the flight simulation software, a division of the module, class hierarchy and operation mechanisms are researched in detail. It shows that class has polymorphism and inheritance, which make the simulation software have good characteristics of expand debugging and maintenance.

The research work of simulation according to specifically UAV system should pay more attention on two typical parameters i.e., the speed and pitch angle which represent ideal environment and disturb the environment with wind, respectively. The simulation platform can lay a foundation for the UAV flight simulator system.

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