

# Design of Helicopter Training Simulator

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**Abstract**—Based on the aerodynamic parameters and control law of certain helicopter, a helicopter training simulator is designed. The recursive execution procedures of the actuators are written by C language, the helicopter equation of state is solved by Runge-Kutta, the navigation calculation module is designed to realize the helicopter navigation. Based on the above steps, the simulating and training functions are realized through designing the human-computer interfaces, which are designed using Microsoft Foundation Classes (MFC). The flight attitude is displayed in the three dimensional scene, which is configured in Vega. The flight data such as attitudes, heading and velocity is displayed in real time by flight instruments, which are designed by Graphics Device Interface (GDI). It is shown that the simulating effect is realistic, and the system achieves the design specification that is very practical.

**Keywords**- Helicopter, Simulator, Visual simulation, GDI

## I. INTRODUCTION

As helicopter has bad static stability, obvious cross-linkage and nonlinear characteristics, with aerodynamic characteristic seriously affected by flight velocity and height, helicopter is a static unsteady system, it is very difficult to drive helicopter. Therefore, autopilot is generally equipped to implement stability augmentation control. It is necessary to design control law to make the helicopter meet quality index requirements in whole flight envelop with strong robustness. Before the flight test, control law must be tested strictly through the simulations. In addition, flight simulation on the ground is also an effective and safe way for training the helicopter pilots. It is a intuitional way to verify the control law using modern simulating tool such as the three dimensional scene[6], which can provides the reliable simulation data for actual flight test. Pilots could experience the process of driving helicopter on the ground through constructing a helicopter simulating and training platform, which provides a virtual driving environment[2], it is significant for training the helicopter pilots safely and effectively, and it is also effective for verifying the flight quality.

## II. THE SYSTEM STRUCTURE

### A. The block diagram of the system

The block diagram of the helicopter simulating and training system is presented in fig.1. The actuators receive the output signals of the control law, which is used to control

the helicopter attitudes, heading and altitude. Based on the aerodynamic parameters and control law of certain helicopter, the recursive execution procedures of the actuators are written by C language, the helicopter equation of state is solved by Runge-Kutta, the navigation calculation module is designed to realize the helicopter navigation. On the basis of above steps, the simulating and training functions are realized through the design of the human-computer interfaces.

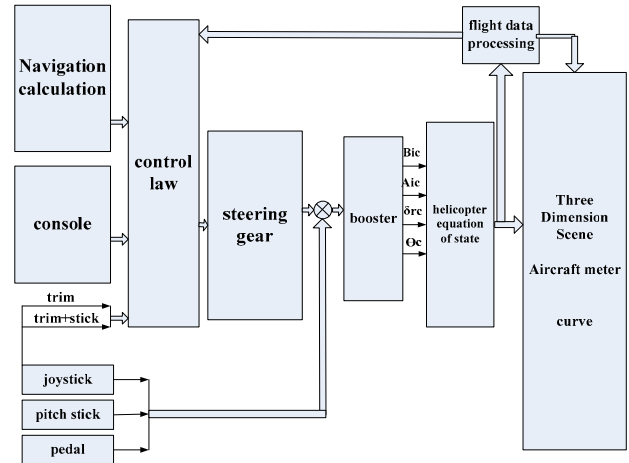


Figure 1. The block diagram of the helicopter training simulator

The functions of the helicopter joystick are realized through the design of the software interfaces, the joystick consists of the trim, pedal and pitch stick. The Vega API functions are called to realize the helicopter three dimensional scene[1]. The interfaces of “virtual meter” and “curve” are realized based on GDI.

### B. Navigation calculation

The purpose of navigation calculation module is to calculate the lateral control signal based on scheduled airline, helicopter speed, position, heading. The lateral control signal is used as roll angle datum to control the coordinated turn automatically. In this paper the navigation control law is presented by formula (1).

$$\gamma_g = K_1 \cdot \Delta d + K_2 \cdot V \cdot \Delta \psi \quad (1)$$

$\Delta d$  is the lateral range,  $\Delta \psi$  is the crab angle,  $V$  is the speed,  $K_1$  and  $K_2$  are the proportionality factors. The formulas for computing  $\Delta d$  and  $\Delta \psi$  are as follows:

$$\Delta d = \frac{(y_{i+1} - y_i)x - (x_{i+1} - x_i)y + y_i x_{i+1} - y_{i+1} x_i}{\sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}}$$

$$\bullet \text{sign}((x - x_i)(y_{i+1} - y_i) - (y - y_i)(x_{i+1} - x_i))$$

$$\Delta \psi = hx - \psi \quad (2)$$

Where  $(x, y)$  is the helicopter coordinate,  $(x_i, y_i)$  is the coordinate of the current voyage point,  $hx$  is the heading angle of the current scheduled airlines,  $\psi$  is the helicopter heading angle.

### C. The helicopter model calculation

The actuators receive the outputs of the control law, which are used to control the helicopter attitudes, heading and altitude. Then the example of the pitch actuator will be given, which is used to introduce how to realize the input and output characteristics of the actuators through writing the recursive procedures. The structure of the pitch actuator is presented in fig.2. It consists of the pitch tandem rudder, parallel rudder and booster.

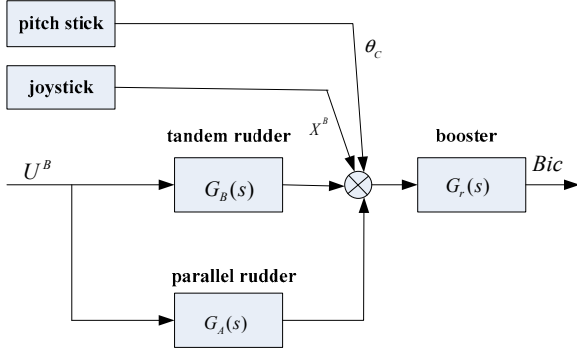


Figure 2. The structure of the pitch actuator

The booster is equivalent to the inertia link  $G_r(s)$ ; the tandem rudder is equivalent to the first-order link  $G_B(s)$ ; the parallel rudder is equivalent to the integral link  $G_A(s)$ .

$$G_r(s) = \frac{1}{T_1 s + 1}, \quad G_B(s) = \frac{a}{s + b},$$

$$G_A(s) = \frac{V^B}{s} \quad (3)$$

Where  $T_1$ ,  $a$ ,  $b$ ,  $V^B$  are parameters,  $\theta_c$ ,  $X^B$  are the outputs of pitch stick and joystick respectively,  $Bic$  is the output of the pitch actuator.

The models of the actuator are discretized by the first order differential as shown in the formula (4),  $T$  is the calculation cycle (20ms).

$$s = \frac{1 - z^{-1}}{T} \quad (4)$$

To obtain the corresponding differential equations of the pitch actuator, the first order differential formula is substituted to the formula (3), the recursive execution procedures of the pitch actuator are written by C language

according to the differential equations. Similarly, the models of other three channels are discretized, the recursive procedures of each actuator are written by C language in the same way.

The helicopter equation of state is given by the following six degree of freedom linear perturbed equations:

$$\dot{x} = Ax + Bu$$

$$y = Cx \quad (5)$$

Where  $x \in R^9$  is state vector,  $y \in R^9$  is output vector,  $u \in R^4$  is input vector,  $A$ ,  $B$ ,  $C$  are real matrices with compatible dimensional. The helicopter equation of state is solved by Rung-Kutta method. The Rung-Kutta step is equivalent to the calculation cycle  $T$ . In order to achieve real-time calculation, a primary timer is defined. All the calculations are completed in the timer each calculation cycle[7].

In order to test the correctness of this method, the practical test is carried out. The testing condition is that the helicopter speed is 35.6m/s, the altitude is 3km, the helicopter takeoff weight is 9000kg, the helicopter initial state values are zero. At the time 3s-5s, a longitudinal cyclic pitch of which the magnitude is 1.5 has been given; at the time 8s-11s, a lateral cyclic pitch of which the magnitude is 1 has been given, the simulation time is 20s. The simulation results are presented in fig.3. The solid lines represent the Rung-Kutta computations, the dashed lines represent the matlab computations, the results satisfy the helicopter characteristics, the computations by Rung-Kutta coincide with the computations by matlab, it is indicated that the Rung-Kutta method can be used for real time simulation.

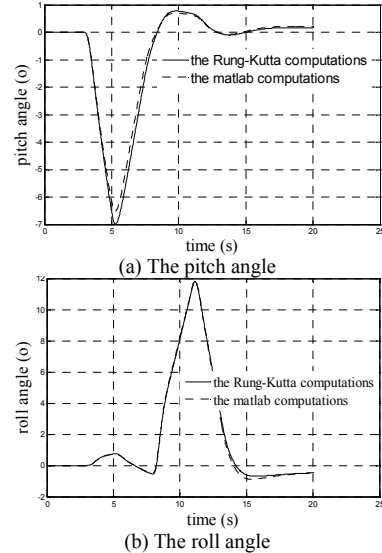


Figure 3. The pitch angle and the roll angle response curves

### D. The design of the system interface

The system interface consisted of “console”, “joystick”, “aircraft meter”, “curve”, “Three dimensional scene”. The

system interfaces are designed based on MFC as shown in fig.4.

(1) “scene” is the interface used to display the helicopter three dimensional visual scene. The three dimensional scene is the important and practical tool in the flight simulation, from which the attitudes and position of the helicopter can be watched obviously.

The three dimensional model of the helicopter, instrument panel and terrain are created in Creator, which is developed by MultiGen company. In order to display flight data dynamically, DOF nodes are set in the models. the rotary wing and the tail rotor of the helicopter need to rotate in the simulation, to realize this effect, a lateral rotating DOF node and a longitudinal rotating DOF node are set in the rotary wing and the tail rotor respectively. DOF nodes are also applied to the instrument panel to realize the real-time display. The Image2ded and Float2ded tools of Creator can be used to obtain the terrain information from the INT and RGB image files directly, all the information about the terrain is stored in the DED files; The float2ded tool can transform the pure data files into DED files directly. Creator can generate the 3D model of the terrain using the DED file [3]. The terrain in this paper is a strait, the helicopter model is Apache model supplied by Creator.

(2) “console” is a interface of the flight console based on MFC. Flight console is one of the major parts of the autopilot, which consists of function buttons and indicating instruments. The flight mode transition and control parameters adjustment can be completed by the buttons and the knobs on the flight console. If the hovering button is pressed down, the helicopter will risen the head and reduce the speed to hover at a certain altitude. The outputs of control law can be watched from the indicating instruments.

(3) “joystick” is a human-machine interface, which is used to simulate the functions of joystick, the functions consist of cyclic pitch, pedaling and blade pitch. A circular region created by GDI is used to capture the input signals of the mouse[5]. When the mouse move into the circular region, its position will be recorded and converted into the position of the control stick. In this way, the function of cyclic pitch is realized. Similarly, the other functions are realized.

(4) “aircraft meter” is the virtual flight instrument interface used to display the helicopter attitudes, heading, speed and altitude.

(5) “curve” is a interface used to display the flight curves and flight path, which is design by the virtual instrument class. Virtual instrument class consists of update function, invalidate function, paint function and GDI drawing function. The update function is used to update the flight data in each calculation cycle, the invalidate function is called to redraw the corresponding window region which is changed with the new data, paint function is responsible for sending WM\_PAINT drawing message, then GDI drawing function starts to redraw the virtual instrument according to the current flight data to realize the real-time flight data displaying[4].

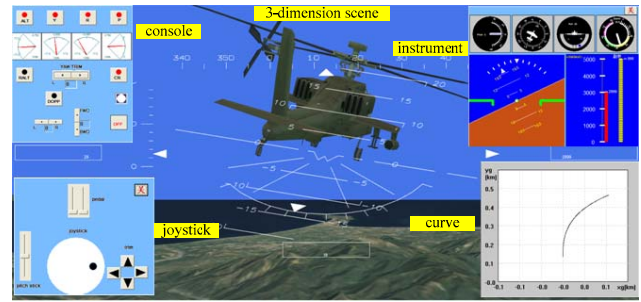


Figure 4. The system interface

### III. SIMULATION RESULTS

#### A. The simulation of navigation

The main task of navigation is to make plane fly with the scheduled airlines. The simulation condition: the helicopter speed is 34m/s, the altitude is 3km, the helicopter initial state values are zero,  $K_1$  is 16,  $K_2$  is 2.3, scheduled airlines are  $[(0, 0), (3, 3), (0, 3), (3, 0)]$ , the unit is km. The flight path is presented in fig.5, the dots represent the voyage points, the line represents the flight path, the helicopter flies according to the scheduled airline, the response process of adjusting the airline is reasonable and quick, which proves the rationality of the navigation control law. The three dimensional scene is presented in fig.6.

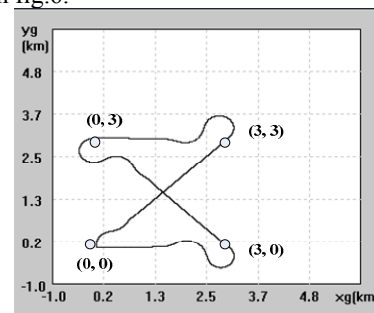


Figure 5. The flightpath in the navigation simulation



Figure 6. The three dimensional scene

### B. The simulation of driving

Pilot can manipulate the helicopter through the flight console and the control stick. The simulation is carried on under the condition that the helicopter speed is 34m/s and the altitude is 3km. Firstly, “pitch” button, “tilt” button and “heading” button are pressed down to get through the function of three-axis stabilization, secondly, the sequent actions: pushing the stick forward, pulling the stick backward, pressing the stick toward right, pressing the stick toward left, pushing the right pedal, pushing the left pedal are performed sequentially. The corresponding responding curves of attitude angles and heading are showed in fig.7. while push the stick forward, the pitch angle is negative, the helicopter noses down; while pull the stick backward, the pitch angle is changed to be positive, the helicopter rises the head; while press the stick toward right, the tilt angle is positive, the helicopter tilts toward right; while press the stick toward left, the helicopter tilts toward left; while push the left pedal, the heading angle is negative, the helicopter turns left; while push the right pedal, the helicopter turns right. The total response process satisfies the characteristics of the aircraft, it is indicated that the function of simulating driving under the given flight state point is realized.

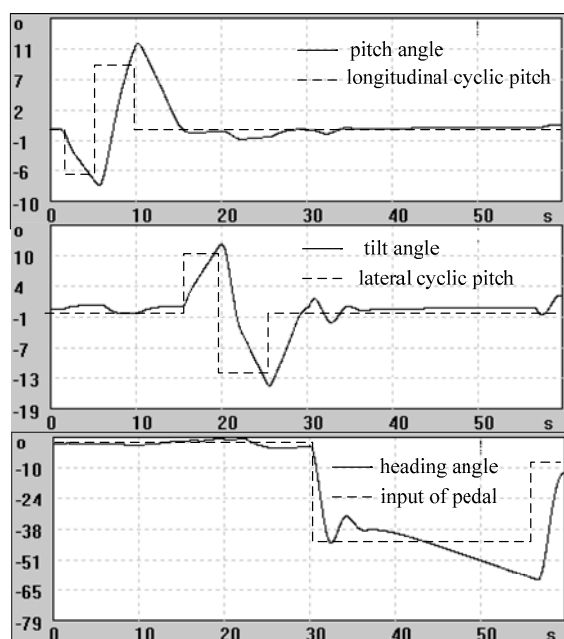


Figure 7. The response curves of attitude angles and heading

### IV. CONCLUSIONS

In this paper, the method to design the helicopter simulating and training system is introduced. The navigation control law is tested through the digital simulation in the system. The actual simulation results indicate that the system has satisfied the requirements of the simulating and training function. The helicopter simulating and training system supplies a virtual helicopter driving platform, which is significant for training the helicopter pilots safely and effectively, and it is also effective for verifying the flight qualities.

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