Application of Intelligence Technology in Super-maneuverable Flight Control

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***Abstract*—This paper introduces the control strategy and method of non-linear dynamic inversion. Depending on the thought of dynamic inversion, the mathematical model of super-maneuverable aircraft is set up and the simulation curves are produced. Through analyzing the curves, we can draw out the feasibility and limitation of non-linear dynamic inversion.This paper introduces below contents :the feasibility of dynamic inversion in super-maneuverable flight; the modeling error and inversion error; the influence on super-maneuverable flight caused by uncertain factors. To solve above problems, the paper points out two kinds of methods. One is fuzzy self-adaptive technology. It describes the characteristic of fuzzy controller and points out its limitation that it can't be used to eliminate the error caused by uncertain factors. The other is neural network technology. It describes the dynamic inversion off-line neural network controller. On-line neural network controller eliminates error. At last the conclusion is gotten that neural network is more advantageous and the development direction of super-maneuverable flight.**

***Keywords*—Super-maneuverable flight, dynamic inversion, fuzzy self-adaptive, neural network**

I. INTRODUCTION

Super-maneuverable flight is also called post-stall maneuver. It is distinct characteristic of the new generation aircraft. Utilizing post-stall maneuver, we can get clear tactics advantage. Post-stall is achieved through increasing attack angle(up to 70 degrees) and rolling around velocity vector. It has below advantages: quick nose turning [1], quick launching missiles and obviating battle missile.

In order to achieve super-maneuverable ability, except engine, vector propulsion, the key is Flight Control. Because this kind of movement needs to break through stall restrict. It involves with problems like great range nonlinear, no constant aerodynamic force and strong coupler. The movement equation of the aircraft is totally multi degree of nonlinear equation. Traditional Small disturbances method can't be applied again. So we need find out a new design method. Dynamic inversion is one kind of appropriate method.

II. DYNAMIC INVERSION TECHNOLOGY

A. *Control strategy of dynamic inversion*

In the 1960's, dynamic inversion technology is becoming mature more and more when it is applied in the control fields. It gets acknowledge extensively. Dynamic inversion method is based upon nonlinear object. Its essential is to transform the nonlinear system to linear structure through nonlinear state feedback and the inversion calculation of control matrix[2]. So we can use traditional linear system method to design control system. It constructs non-linear functions to eliminate non-linear dynamic inversion to eliminate objects' nonlinearity. Then based upon the "false" linear system, we can add corresponding feedback and plus to achieve the desired system response.

There are two kinds of control methods for non-linear dynamic inversion: output feedback and state feedback. It is difficult for output feedback because we need calculate its differential coefficient of every rank. It can't make use of common sensors to measure the aircraft's state variables to construct feedback. What's more, it is very difficult to solve the equations with multi non-linear differential coefficient. Usually we adopt the second type: state feedback inversion.

Directly applying state feedback method, we need to solve the Full Inversion. That is to say, we must satisfy the condition that the counts of control variables and state variables are equal. But it is impossible in the Flight Control System. To avoid this shortage, we combine the non-linear inversion method and the singular perturbation theory.

B. *Model of aircraft in super-maneuverble condition*

Its mathematical model can be described by below state equations.

$$\dot{V} = \frac{1}{M}[-D + (Y + Y_T)\sin\beta - Mg\sin\chi] + \frac{1}{M}(T_x\cos\beta\cos\alpha + T_z\cos\beta\sin\alpha) \tag{1}$$

$$\dot{\chi} = \frac{1}{MV}(L\cos\Phi - Mg\cos\chi) - \frac{1}{MV}(Y + T_y)\cos\beta\sin\Phi) +$$

$$\frac{T_x}{MV}(\sin\Phi\cos\beta\cos\alpha+\cos\Phi\sin\alpha)+$$
$$\frac{T_z}{MV}(\sin\Phi\sin\beta\sin\alpha-\cos\Phi\cos\alpha) \quad (2)$$

$$\dot{\psi}=\frac{1}{MV\cos\chi}L\sin\Phi+\frac{1}{MV\cos\chi}(Y+T_y)\cos\Phi\cos\beta+$$
$$\frac{T_x}{MV\cos\chi}(\sin\Phi\sin\alpha-\cos\Phi\cos\beta\cos\alpha)-$$
$$\frac{T_z}{MV\cos\Phi}(\cos\Phi\sin\beta\sin\alpha+\sin\Phi\cos\alpha) \quad (3)$$

$$\dot{\alpha}=q-\tan\beta(p\cos\alpha+\gamma\sin\alpha)+$$
$$\frac{1}{MV\cos\alpha}(-L+Mg\cos\chi\cos\Phi)+$$
$$\frac{1}{MV\cos\beta}(-T_x\sin\alpha+T_z\cos\alpha) \quad (4)$$

$$\dot{\beta}=(-\gamma\cos\alpha+p\sin\alpha)+$$
$$\frac{1}{MV}[(Y+T_y)\cos\beta+Mg\cos\chi\sin\Phi)]+$$
$$\frac{1}{MV}(-T_x\sin\beta\cos\alpha-T_z\sin\beta\sin\alpha) \quad (5)$$

$$\dot{\Phi}=\sec\beta(p\cos\alpha+\gamma\sin\alpha)+$$
$$\frac{1}{MV}(\tan\beta+\tan\chi\sin\Phi)+$$
$$\frac{Y+T_y}{MV}\tan\chi\cos\Phi\cos\beta-\frac{Mg}{MV}\cos\chi\cos\Phi\tan\beta+$$
$$\frac{T_x\sin\alpha-T_z\cos\alpha}{MV}(\tan\chi\sin\Phi+\tan\beta)-$$
$$\frac{T_x\cos\alpha+T_z\sin\alpha}{MV}(\tan\chi\cos\Phi\sin\beta) \quad (6)$$

Because the change of every variables have distinct difference in time domain, we can classify the state variables into very fast variables (rolling angle rate p, pitch angle rate q and yaw angle rate γ), fast variables (attack angle α, sideslip angle β and rolling angle ϕ) and slow variables (velocity V, flight path angle χ and climb angle ψ), decompose the nonlinear equation group into three different time scale sub-systems. For every sub-system we make use of dynamic inversion method to find out control instruction. When finding the roots of very fast variables sub-system, we can think the other two sub-systems' variables as constants. In the same reason, when finding the roots of fast variables sub-system, we can treat the other two sub-systems' variables as constants [3]. In this method, the nonlinear, strong coupler effect and multi variables' system design can be simplified. Shown as figure 1.

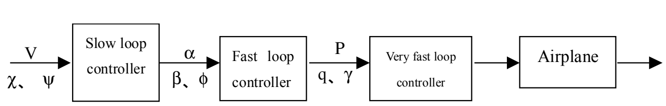

Figure 1. Principle block diagram with dynamic inversion

1) The control law design for very fast loop.

Below is the desired state equation:

$$\dot{x}_1=f_f(x)+g_f(x)u \quad (7)$$

here, $\dot{x}_1=\begin{bmatrix}\dot{p}\\ \dot{q}\\ \dot{\gamma}\end{bmatrix}$, $u=\begin{bmatrix}\delta_1\\ \delta_2\end{bmatrix}$

assume $u=g_f^{-1}(x)[-f_f(x)+v_f]$, and $v_f=\omega_f(x_{1c}-x_1)$

Block diagram is shown in diagram 2.

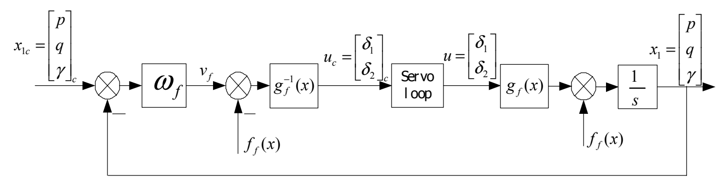

Figure 2. Very fast loop block diagram

2) The control law design for fast loop

Below is the desired state equation:

$$\dot{x}_2=f_m(x)+g_m(x)u_m \quad (8)$$

here, $\dot{x}_2=\begin{bmatrix}\dot{\alpha}\\ \dot{\beta}\\ \dot{\Phi}\end{bmatrix}$, $u_m=x_2=\begin{bmatrix}p\\ q\\ \gamma\end{bmatrix}$

assume $u_m=x_2=g_m^{-1}(x)[-f_m(x)+v_m]$,

and $v_m=\omega_f(x_{2c}-x_2)$

Block diagram of fast loop is shown in diagram 3.

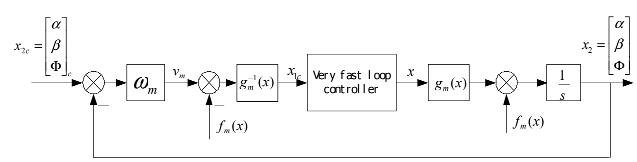

Figure 3. Fast loop block diag

3) The control law design for slow loop

Below is the desired state equation:

$$\dot{x}_3=f_s(x,u_s) \quad (9)$$

here, $\dot{x}_3=\begin{bmatrix}\dot{V}\\ \dot{\chi}\\ \dot{\psi}\end{bmatrix}$, $u_s=\begin{bmatrix}\alpha\\ \beta\\ \Phi\\ T\end{bmatrix}$

assume $u_s = f_s^{-1}(x, u_s) v_s$, and $v_s = \omega_s (x_{3c} - x_3)$

Block diagram of fast loop is shown in diagram 4.

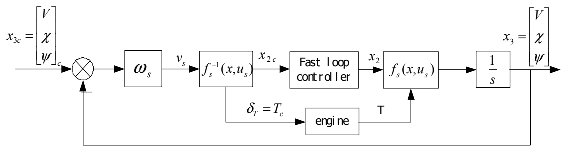

Figure 4. Slow loop block diag

C. Simulationl of aircraft in super-maneuverble conditio

This paper chooses classical Herbst movement to testify the designed Flight Control System. It is one kind of 180^0 turning. In turning, the change of pitch angle, velocity and roll angle is much greater than normal. Below simulation is drawn under the condition of initial velocity 100m/s and height 4000m.

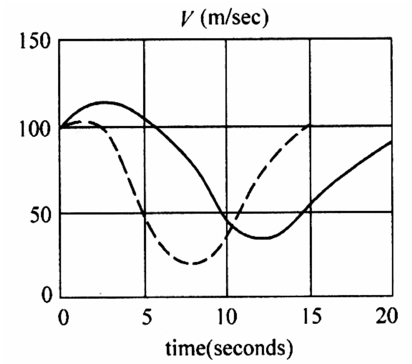

Figure 5. The velocity

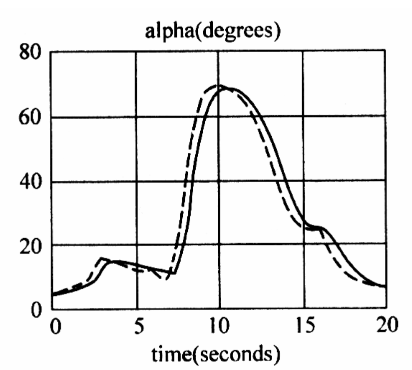

Figure 6. Pitch instruction and its response

The real lines in the diagrams represent the velocity, pitch angle and roll angle through the calculation of dynamic inversion. Diagram 5 shows that the velocity is changing. In 12 seconds, drop from 100m/s to 30m/s, then rise. Diagram 6 shows the maximal pitch angle exceeds 60^0. To make the aircraft to slow down more quickly, when increasing the pitch angle, turn along the axis of velocity vector. When roll angle arrives at 140^0, Diagram 7 shows the aircraft turn in minimal turning radius(130m) and gradually get back its height.

The above simulation curves prove that the super-maneuverable system designed by non-linear dynamic inversion is practical. And also they show limitation of dynamic inversion technology. (1) Research object must have exact mathematic model;(2) It can't be applied in non smallest phasic system;(3) Its premise is that we can get full state feedback;(4) It is not easy to have robust analysis;(5) It has model error and inverse error. Literatures [1] to [6] prove above.

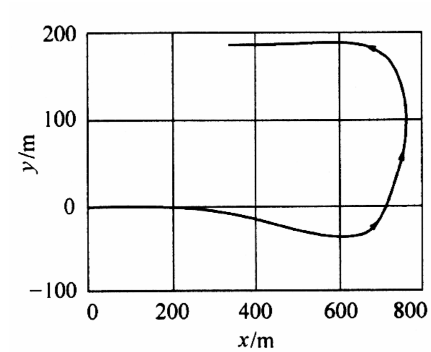

Figure 7. Level projection of aircraft

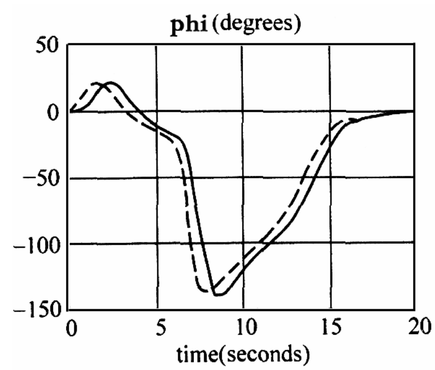

Figure 8. Roll instruction and its response

In order to eliminate aircraft modeling error, inversion error and the influence by uncertain factors, there are two kinds of control method: In the mathematic model of every loop controller there is some uncertain items, so we need to design a controller in the system, the controller can eliminate the system's uncertainty.

This kind of method is called fuzzy self-adaptive control. The other method is to design reasonable slow loop controller. Another method is to design reasonable slow loop controller to eliminate inversion error. The kind of method is called neural network control.

III. FUZZY SELF-ADAPTIVE TECHNOLOGY

Fuzzy self-adaptive technology is applied in super-maneuverable flight. Its essential is to design a fuzzy controller based upon nonlinear dynamic inversion. Utilizing the controller, we can eliminate the uncertain factors of the system's inner loop. The controller is designed upon experience and expert knowledge. So the influence of uncertainty of model will decrease. So fuzzy controller has strong power to inhibit the influence of the system's output caused by inner parameters. To every kind of models and working conditions, it has some robust. It is often used on such control problems that the model is not quite exact. On the other hand, it is self-adaptive, it can adjust controller's parameters depending on error and variety of surroundings. It is robust.

Literature [4,5] proves in theory that the error based nonlinear dynamic inversion fuzzy self-adaptive is convergent. The simulation result shows it has good instruction tracking characteristic. It can effectively compensate the error caused by model uncertainty. So it can make up the shortcoming that nonlinear dynamic reversion need exact mathematic model.

IV. NEURAL NETWORK TECHNOLOGY

Analyzing from control theory, if we design the slow loop controller properly in diagram 1, the errors include aircraft modeling error, inversion error and uncertainty can be eliminated. Based upon this idea, we apply the control in diagram 8 for the slow loop, and apply simple dynamic inversion for other loop.

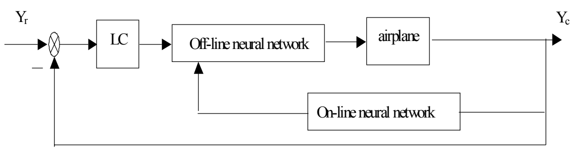

Figure 9. Principle block diagram with neural network

The neural network dynamic inversion technology shown in diagram 8 is the most often adopted method in now times. It includes two neural network. One off-line neural network is used to realize the aircraft's dynamic inversion. The other on-line neural network compensates the inversion error.

We can eliminate inversion error on time under the condition that uncertainty factors are not clear. The neural network can fully reach inversion. The off-line neural network is one part of the whole controller, the other part is composed of LC circuit. Linear controller's design can enhance system's dynamic performance. Or the other part is also composed of on-line neural network to enhance system's dynamic performance. super-maneuverable flight can have better effect. Literature [6] proves above.

V. CONCLUSION

Fuzzy self-adaptive dynamic inversion method can eliminate the influence caused by uncertainty factor in some degree, but the error caused by nonlinear function can't be removed. The neural network works in different way. The modeling error, inversion error and error caused by uncertainty factors can all be compensated through neural network. So neural network inversion method has broader fields to apply.

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