REAL TIME EXPERT CONTROL OF A FLIGHT VEHICLE CONTROL SYSTEM

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ABSTRACT

In this paper, a real time expert controller of a flight vehicle is studied. In the RTEC, a nonlinear space model is used to get hierarchic predictive control law. To get good control performance, an expert system is set up to choose the correct controlled model and to adjust some key parameters in the RTEC. Simulation is introduced in the paper.
KEYWORDS:expert control,hierarchic predictive control,flight engineering

1. INTRODUCTION

Generally, a flight vehicle control system is a nonlinear, time-varying and high dimensional system. Its controller design is a difficult problem. One solution to the problem is changing it into a linear model. Then, we can design its controller by means of modern control theory. However, the method has many disadvantages:

(1) T_{to-go}(the time from present to final point) should be known or estimated. Even a little bias in T_{to-go} may lead to a unacceptable control performance. And there is not a efficient way to estimate T_{to-go}[1].

(2) Riccati equation(or TPBVP problem) in optimal control should be solved on line. This is difficult due to its long calculating time and large computer capacity.

(3) Linear model may sometimes present the flight vehicle poorly due to its complex flight condition. This will lead to poor control performance unsuspiciously.

To overcome these disadvantages, predictive control concepts has been used[2]. In the predictive control scheme, a nonlinear control model was used to design its controller directly. Simulation has proved that this controller design method is very efficient. However, how to improve its control performance in complex flight condition is still an open problem[4].

In this paper, a real time expert controller(RTEC) is studied to design a flight vehicle control system.

Expert control can use heuristic logic and provide new functions in a control system. A direct expert control has been proved very efficient to some systems which mathematical models are difficult to obtain. However, knowledge tell us that optimal control is excellent to some well understood problem. Thus, we should combine expert control with optimal control to solve some complex control problems. Those problems can be formulated with mathematical models under some conditions. From them, their optimal control law can be obtained. When those conditions change, their control model and/or some key parameters should be adjusted by an expert system to get good control performance.The RTEC is a good example of those problems.

According to the principle of higher intelligence, lower precision[3], the RTEC is divided into two levels(see figure 1).

The higher level is an expert system used to manage and coordinate the lower level intelligently. The lower level is a hierarchic optimal predictive controller, which is used to control the flight vehicle directly.

This paper has four parts. After the brief introduction, the background of the flight vehicle and its hierarchic controller design of lower level in the RTEC are presented. Then, we discuss the expert system in the RTEC in detail. At last, somulation and its result are introduced.

2. HIERARCHIC CONTROLLER IN THE RTEC

2.1 Background And Model Of The Flight Vehicle Control Problems

The problem we studied is an interception problem. In order to ensure its interception result, high hit precision and suitable terminal attitude angle are required. A general method to the problem is changing the interception problem into a LQG problem. Then, a control law can be obtained by means of modern control theory. However, the method has many drawbacks in anti-interference, realization, efficiency, etc[1]. Thus, we have presented a new control scheme to the problem[4].

At first, an ideal flight trajectory should be decided(see figure 2).

The ideal flight trajectory can be divided into three stages: OA stage is called as height-adjusting stage. Its purpose is to adjust the flight vehicle to a suitable height to get a required collision attitude angle; AB stage is called as turn-diving stage; BT stage is called as straight flight stage. Its purpose is to adjust the flight vehicle to get a high hit precision

In the ideal flight trajectory, point O is the initial control point; T is hold on the target. The whole ideal flight trajectory will move following the target in the space. The position of point A and B shoule be decided in the real time.

The flight vehicle interception problem we studied can be formulated as a nonlinear state equation with ten dimensions. Its control purpose is to ensure the flight vehicle flying along the ideal trajectory all time. Since the ideal trajectory has 3 stages and each stage has its own interception model, the controller must analyse the stage which the flight vehicle is in and select its correct model to get control law. All these tasks should be done in the real time.

The controlled model of the flight vehicle interception problem can be presented as:

$$X_{k+1}=A^{l}(X_k,k)X_k+B^{l}(X_k,k)U_k+D^{l}(X_k,k)$$
$$|U_k|<U_d \tag{1}$$
$$l=1,2,3;\ k=0,1,2,\ldots$$

where $X_k=(x_{1k},x_{2k},\ldots,x_{10k})^T$ is the state vector; $U_k=(u_{1k},u_{2k},u_{3k})^T$ is control vector; U_d is the bound of the control vector, $U_d>0$; $A^{l}(\cdot,\cdot)$, $B^{l}(\cdot,\cdot)$, $D^{l}(\cdot,\cdot)$ are matrix functions of state vector and their dimensions are 10×10, 10×3, 10×1 respectively; $l=1,2,3$ indicates the interception model during stage OA, AB and BT respectively.

To the flight vehicle control problem, we present an optimal predictive control index function as:

$$J_k=\sum_{i=1}^{N}\|X_{pk+i}-X^{*}_{pk+i}\|^2_{Q_k} \tag{2}$$

where X_{pk+i} is the predictive value of the state vector at time k+i; X^{*}_{pk+i} is the ideal value of state vector at time k+i; N is the horizon of state prediction; $Q_k=\mathrm{diag}(0,0,q_3,1,0,0,q_7,1,q_9,1)$, $(0<q_i<1,\ i=3,7,9)$

2.2 Design Of The Hierarchic Controller

Because the flight vehicle control system is a high dimensional system, it would need large amounts of computer time and capacity to get control law from equation(1) and (2). Thus, hierarchic control concepts should be used to realize the purpose of real time control.

The flight vehicle control system was divided into three subsystems. They are consistent with yaw, pitch and roll canals in the flight vehicle. Those subsystems can be described as:

$$X_{tk+1}=A_t(X^{0}_{k},k)X_{tk}+B_t(X^{0}_{k},k)u_{tk}+D_t(X^{0}_{k},k)$$
$$X^{0}_{k}=X_k \tag{3}$$
$$t=1,2,3$$

where $X_{1k}=(x_{1k},x_{2k},x_{3k},x_{4k})^T$

$X_{2k}=(x_{5k},x_{6k},x_{7k},x_{8k})^T$

$X_{3k}=(x_{9k},x_{10k})^T$

At the same time, the optimal index \nction (2) can be decomposed as follows:

$$J_k=\sum_{t=1}^{3} J_{tk}$$
$$J_{tk}=\sum_{i=1}^{N}\|X_{tpk+i}-X^*_{tpk+i}\|^2_{Q_{tk}} \qquad (4)$$

'here X_{tpk+i} and X^*_{tpk+i} are the predictive .nd expected value of state in the subsys- .em t at time k+i. $Q_{1k}=\mathrm{diag}(0,0,q_3,1)$, $Q_{2k}=\mathrm{diag}(0,0,q_7,1)$, $Q_{3k}=\mathrm{diag}(q_9,1)$.

According to equation (3) and (4), we :an get hierarchic predictive control law of the flight vehicle by means of the algo- ·ithms described in ref[4]. The optimal predictive control law U_k^{op} can be presented is:

$$U_k^{op}=U(X_k,N,Q_k,A^l(\cdot,\cdot),B^l(\cdot,\cdot),D^l(\cdot,\cdot),U_d\ ) \qquad (5)$$

Simulation and experience show that the value of parameter N and Q_k can influence the control performance significantly. The value of those key parameters should be determined and selected on-line. Therefore, an expert system was set up to finish those tasks.

3. THE EXPERT SYSTEM IN THE RTEC

There are two purpose to set up an expert system in the RTEC. The first is to determine the flight stage on-line to select a correct control model from model set. The second is to analyse the control performance and adjust the value of key parameters in the real time. So, an expert system consisting of four parts (see figure 1) is set up.

3.1 Knowledge Base--Production Rules

3.1.1 <u>Select correct modol from model set</u> The flight vehicle has three flight stages(see figure 2). In different stage, the flight vehicle has a different control model. Thus, a correct model should be selected from model set to get control law.

According to some principles[4], some key parameters in the ideal trajectory can be determined previously. They are the height of stage OA(H); the horizonal distance between point A and T(X_{AT}); the angle where the flight vehicle changing its flight stage from stage AB to stage BT (θ^o).

In the expert system, the model selection tasks can be done according to following rules:

(R1) If the distance between the flight vehicle and the target X_{MT} is larger than X_{AT}, then the flight vehicle is in stage OA and model 1 should be selected(l=1).

(R2) If $X_{MT}\leq X_{AT}$ and $|\theta|>\theta^o$, the flight vehicle is in stage AB and model 2 should be selected(l=2).

(R3) Once $|\theta|<\ \theta^o$ happen, the flight vehicle has entered stage BT. Thus, only model 3(l=3) can be chosen after the moment.

3.1.2 <u>choose key parameters in the controller</u> Some parameters in the controller can influence the control performance significantly. Those parameters are the state prediction horizon N and the weight matrix Q_k. Let us introduce their influence first.

The influence of parameter N has two aspects. If N value is too large, the precision of state prediction $X_{pk+i}(i=1,2,..N)$ will be low. Thus, a bed control performance may be got. On the other hand, if N value is too small, the controller will be less stable and a oscillation around the ideal trajectory may happen. Besides, the value of N should be determined according to the level of model precision. If the level is high, N value can be a little large and this will not creat a great state prediction error. If the level is low due to some unpredictive interference, N value must be adjusted smaller to ensure the precision of state prediction. Of course, since the controller will be used in real time, the computer calculating time needed is also an important factor to determine the value of N in the RTEC.

From experience and simulations, the minimum and maximum value of N can be determined. Then, N can be chosen in a definite parameter set N_s according to the prediction precision of some important states. Those states are x_{3k}, x_{7k}, x_{9k}. The adjusting

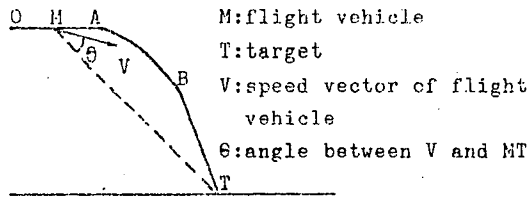

Fig.2 The ideal flight trajectory of the flight vehicle

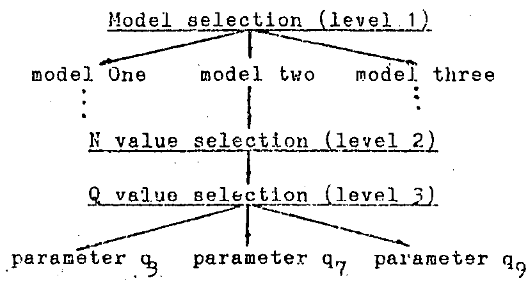

Fig.3 The structure of production rules