Technique of Predictive Function Control of Reference Path Based on Fuzzy Inference

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Abstract — **In the system of terrain following, after planning the optimal reference path, the key problem is the design of controller. in order to get simple and precise controller, by adopting predictive function control to calculate control instructions and applying fuzzy inference to compensate the controlled quantity, namely, control quantity equals the control quantity of predictive function control plus fuzzy compensating quantity, hence, reasonable predictive path control system is designed to make fighter track the planned optimal reference path automatically, plenty of numerical simulation referring to various typical terrain show that the scheme is feasible.**

Key words —**reference path, predictive function control, fuzzy inference, numerical simulation**

I. INTRODUCTION

The future advanced path tracking system began to be studied early in 1970s, for example, the Dr. Funk, from engineering institute of air force of America, had presented the optimal path's tracking scheme of third spline function, it is actually a question of height control, the design of its optimal controller needs not only to take advantage of the high order derivation of the sampling point's height H on the reference path to the level distance, but also to compute a series of reference status quantity, furthermore, in the process of reconstructing path sampling points, except for computing the height of sampling point, a large amount of derivation needs to be computed, the complex calculation makes the scheme too hard to realizing real processing on aircraft. In order to attain the controller with both sample and precise characteristics, the method of Predictive Function Control (namely PFC) is adopted in this paper. The PFC is a new predictive control algorithm based on the research of predictive functional control fundamental, it has the characteristics of sample algorithm and small calculating quantity as well as rapid tracking. For the purpose of promoting the robustness of the PFC, the method of fuzzy inference is adopted to compensate the error, namely, control quantity equals the control quantity of predictive function plus fuzzy compensating quantity, hence, a reasonable control system of predictive path is designed to certify not only a good safety of aircraft but also a strong robustness of the system[1], [2].

II. PREDICTIVE FUNCTION CONTROL OF REFERENCE PATH

Predictive function control, which has three characterristics of general predictive control, namely predictive model and revolving optimizing as well as feedback correcting, pays more attention in the construction modality of control quantity than other predictive control algorithm, and makes the control quantity relate to a set of corresponding process characteristic and function of tracking supposed value, hence, the calculated control quantity of every moment equals the linear combination of a set of preceding selected functions, which are called basis functions, therefore, the corresponding control quantities are attained by putting the known process response into the optimizing calculation of object function and getting the power coefficient of each basis function. [3], [4]

A. Mathematical description

For the purpose of convenience, the predictive process model of PFC adopts the parameter model of dispersing status equation, its description of dispersing status equation is [5]:

$$\begin{cases} X(k) = AX(k-1) + Bu(k-1) \\ X(0) = X_0 \\ Y(k) = CX(k) \qquad k = 1,2,\cdots \end{cases} \tag{1}$$

The selection of basis function relates to process characteristic and tracking supposed value, and control quantity is taken as the linear combination of basis function, such as parabola, slope function and jumping function and so on.

$$u(k+i) = \sum_{n=1}^{N} \mu_n f_n(i) \qquad i = 1,\cdots,P-1$$

In the equation: $u(k+i)$ is the control quantity at the moment of $(k+i)$; $f_n(i)$ is the value of basis function in the sampling period i; N is the number of basis functions; P is the length of optimized time field; μ_n is linear combination coefficient and needs to be optimized calculation.

The optimal reference path according to index law variance is introduced

$$\omega_r(k+i) = r(k+i) - \alpha^i[r(k) - y(k)]$$

In the equation: $\omega_r(k+i)$ is the value of optimal reference path at the moment of (k + I); $r(k +I)$ is the supposed tracking value; $y(k)$ is the output measure value of controlled object at the moment of k; $\alpha = e^{-\frac{T_s}{t/3}}$, $0 \le \alpha \le 1$; T_S is sampling period ; t is closed lop response time.

Predicting the process output at the moment (K+I):

$$\hat{y}(k+i) = y_m(k+i) + e(k+i) \quad (2)$$

In the equation: $y_m(k+i)$ is the predictive model output; $e(k+i)$ represents the predictive error between process and model.

The optimized object function minimizes the square difference between predictive process output

On the fitting points (the number is s) in selected predictive time field (H) and reference difference [6].

$$J = \sum_{i=1}^{s} \{y(k+i) - \omega_r(k+i)\}^2 = \sum_{i=1}^{s} \{\mu^T y_m - d(k+i)\}^2$$

In the equation:

$$\mu = [\mu_1, \mu_2, \cdots \mu_N]^T$$

$$y_m = [y_{m1}(i), y_{m2}(i), \cdots, y_{mN}(i)]^T$$

$$d(k+i) = r(k+i) - \alpha^i [r(k) - y(k)] - e(k+i)$$

Fitting points are dispersing points between 0 and T, and need determine in advance, its numbers shall be greater or equal the numbers of basis functions.

To minimize the performance J index and get cofficient μ , namely

$$\frac{\partial J}{\partial \mu} = 2[(Y_m Y_m^T)\mu - Y_m d] = 0$$

In the equation: Y_m is a matrix, its line is y_m ; namely

$$d = [d(k+1), d(k+2), \cdots, d(k+s)]$$

hence $\mu = (Y_m Y_m^T)^{-1} Y_m d$

so $\mu(k) = \sum_{n=1}^{N} \mu_n f_n(0)$

B. Selection of several parameters

The main factors to influence system's closed loop performance and stability lie in the basis function's number N at intervals of controlled sampling and time field length P of the future predictive optimizing, by comparison, the biggest inference is made by parameter P.

In the simulation research of the system, P can't be less than the system's order n, or else it is hard to stabilize the closed loop system, but when P is greater than (2n-1), the system performance is difficult to make a obvious improvement, so, the general region is $n \leqslant P \leqslant (2n-1)$; The influence of function's number N on system is wonderful, if N = 1, the system will become one step preceding prediction, and oscillate between output sampling points, so, comparatively advisable selection is N=n; with regard to control sampling period (T_S) it is related to each system itself and doesn't be discussed here.

When performing numerical simulation, if aircraft adopts complete longitudinal linear equation, and terrain is random, the selections of above several parameters are: T_S=0.5; N=4 ; P=7. According to the simulation results, the tracking of flight path is comparatively rational.

III. FUZZY COMPENSATION

By assuming that $e(k)$ and $e_c(k)$ are respectively error and error rate of process output at sampling moment, and process exists pure time delay of d steps, the control quantity of fuzzy compensation is determined by $e(k+d)$ and $e_c(k+d)$, $e(k+d)$ and $e_c(k+d)$ can be calculated by preditive model (2) and reference path ω_r, preditive model (2) is determined:

$$e(k+d) = \omega_r(k+d) - y_m(k+d)$$

$$e_c(k+d) = e(k+d) - e(k+d-1)$$

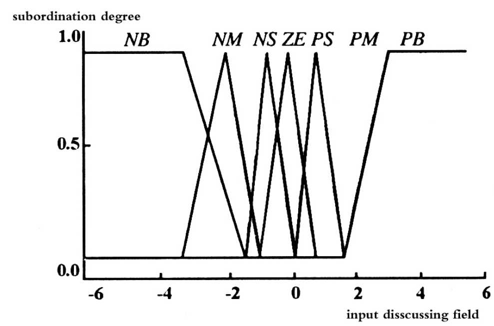

Figure 1. The subordination function of fuzzy variable

The subordination function of two input fuzzy variables and compensating quantity of output control is triangle shape (see Figure.1). Becase adopting uneven distributing contributes to improve the system's control precision, seven fuzzy subsets are adopted: PB, PM, PS, ZE, NS, NM, NB. The fundations of instituting fuzzy law are as follows: on condition that both e and e_c are positive maximums at the moment (k+d), it is illustrated that error has a trend of augmenting further, the determinations both process input is too small and controller's output shall augment can be make at the moment k, $\triangle u$ shall be the positive maximum; on condition that e is the positive maximum and e_c is zero, it is illustrated that the trend of error varying is stable and control quantity can drop a little, $\triangle u$ shall be middle; in case that c is the positive maximum and e_c is the negative maximum, it is illustrated that error has a decreasing trend and control quantity can drop to the minimum, $\triangle u$ shall be positive minimum. Conversely, on condition that both e and e_c are negative maximums at the moment (k+d), the determinations both process input is too big and controller's output shall minish can be make at the moment k, $\triangle u$ shall be the negative maximum. By using the same analyzing method, the fuzzy correcting rules of control quantity are got on other conditions, hence, fifty pieces of rules in total are established. Adopting centroid method solves fuzzy can get $\triangle u$, namely, the sum of $\triangle u$ and preditive control quantity is the control quantity of process input.

IV. REALIZATION OF NEW-TYPE PREDITIVE FUNCTION CONTROLLER

A. A least squares algorithm of time-varying forgetting factor of reasoning by recurrence

According to the preditive model of equation (1), a least squares algorithm of time-Varying forgetting factor of reasoning by recurrence is got, and its flow figure of algorithm program is Figure.2.

B. Realization of new-type preditive function controller

To get the estimating model equation (1) by using a least squares algorithm of time-varying forgetting factor of reasoning by recurrence to discern parameters, the control signal $u(k)$ of new-type preditive function controller based on fuzzy compensation can be got according to the estimating model equation, eventually, taking the control signal as the input of controlled process can create corresponding output, then, the parameters can be discern by sampling input and output data.

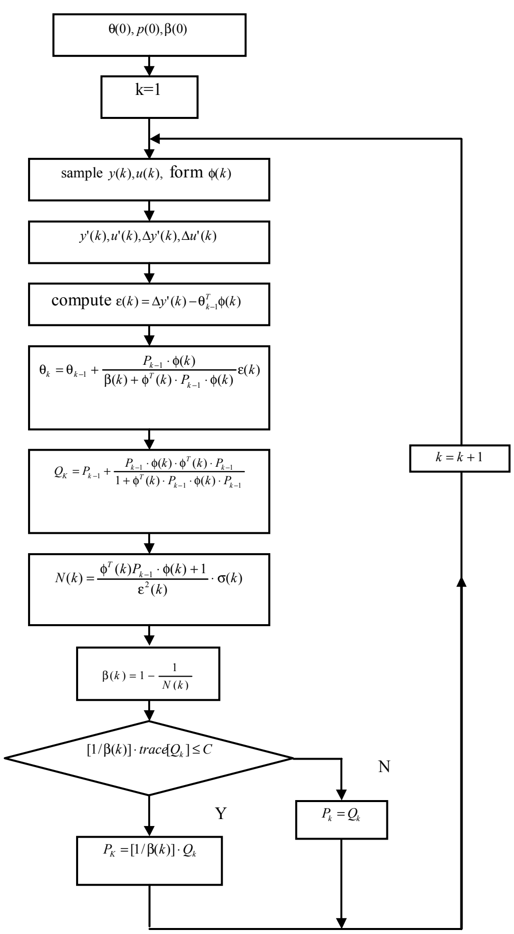

Figure 2. The program flow chart by using time-varying forgetting factor to discern system parameter

V. NUMERICAL SIMULATION

When numerical simulation is performed on IBM-PC, aircraft adopts complete longitudinal linear equation, and various random terrains are selected. With a view to be more straightforward, the reference path H_1 and tracking path H_2 referring to certain random terrain are simultaneously displayed in Figure.3. When the aircraft follows the terrain, the height error *HER* of path tracking is in Figure.4.

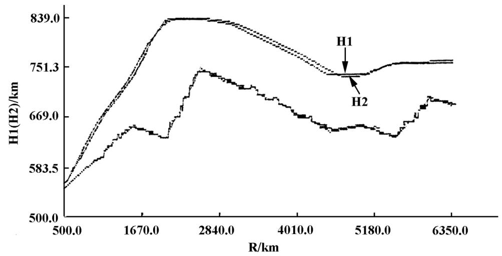

Figure 3. Reference path H_1 and tracking path H_2 of random terrain

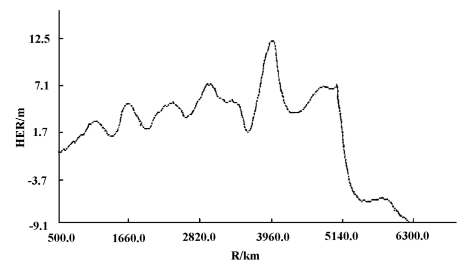

Figure 4. The height error of aircraft's path tracking

VI. CONCLUSION

According to numerical simulation results, the path tracking is comparatively ideal, when the aircraft crosses vertex, the path tracking error is comparatively small and doesn't surpass 3 meters, besides, the normal overloads of the aircraft are all in permitting extension, hence, both airman comfort and aircraft safety certified. Simulation experiments manifest that the scheme which combining predictive control with fuzzy compensation make the aircraft track the reference path is feasible.

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