A method of reliability modelling based on characteristic model for performance digital mock-up of hypersonic vehicle

Zhang Feng[1, 2*], Xue-Hui Feng[1, 2]

[1] *School of automation, Northwestern Polytechnical University, Xi'an 710072, China*

[2] *School of Information Engineering, Yulin University, 719000, Yulin, China*

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Abstract

In order to grasp the complexity of the hypersonic vehicle dynamic characteristics, create its reliability control model, for the mathematical model of hypersonic vehicles is highly nonlinear and strong coupling, introduced the object-oriented modelling method, design a neural network, Petri control algorithm based on characteristics model, the mathematical model of the nonlinear is transformed into the equivalent linear model with control design requirements. And through the appropriate transform, design of the hypersonic vehicle dynamic inversion control system, building performance prototype reliability model based on Petri net, can stabilize the system, get decoupled affect purposes. Simulation results show that the performance digital mock-up reliability model is high accuracy, robustness, anti-jamming capability, has a good dynamic and steady-state performance.

Keywords: hypersonic vehicle, performance digital mock-up, characteristic model, reliability, flight control

1 Introduction

Nowadays, the hypersonic vehicle model and control has become a hot topic in the field of aerospace control, however, due to the lack of wind tunnel testing ground equipment, and flight test validation of hypersonic atmospheric properties is difficult, it is difficult to estimate; aircraft aerodynamic parameters cannot be experimentally means of access. Existing hypersonic aerodynamic parameters used in the model vehicle are basically simulated by the software platform for the try to simulate the real flight environment; the model also added a wide range of variants of unknown parameters and uncertainties. Hypersonic aircraft simulate these nonlinear, uncertainties, strong coupling characteristics of control theory and engineering presents a great challenge for the control of hypersonic aircraft, domestic and foreign scholars have used almost all kinds of advanced control theory [1].

The purpose of modelling is to in-depth analysis system, to facilitate control system design, based on the principles of regulation and modern control theory, are generally required before performing the first controller design modelling, based on the analysis of dynamic characteristics of an object, create the accused Mathematical model of the object. According to the mathematical model of the object dynamics controller design method in control theory and practical applications has played a significant role, however, with the continuous development of science and technology and production, the controlled object structure more complex, precise Dynamic modelling is becoming increasingly difficult; hand controller design as simple as possible in meeting the performance requirements of the situation. Academician Wu Hongxin is based on the above reasons, in twentieth century put forward the idea of characteristic modelling. The basic idea of characteristic modelling is: for high order complex object, in order to meet the control performance requirements, how to design a low order controller, that is to say to seek a kind of how objects modelling becomes simple, in order to facilitate the method of low order controller design [2].

2 Modelling method of object-oriented characteristic

2.1 FEATURE MODELLING CHARACTERISTIC

Traditional mathematical model of the system is usually use the time of continuous or discrete description and use mathematical formulas strictly controlled object depicts the static and dynamic performance. The characteristic model is introduced to describe the complex system characteristic quantity is unable or difficult to accurate mathematical modelling, using feature key points of system and key information are described, from another point of view, generally reflect the static and dynamic performance of the system. For a better understanding of characteristic modelling, here are a few basic concepts.

Define the characteristics of the model includes two points: First, it describes the dynamic behaviour and characteristics information, characterizing feature model is noteworthy here is that the whole system and not just the controlled object, including environmental information and control tasks belong to feature models:

* ***Corresponding author*** e-mail: tfnew21@sina.com

second, the characteristics of the system model to quantitatively characterize the key points and critical information, the system can be broadly reflect the static and dynamic performance. Third, though the model is accurate modelling features, but do not lose the characteristic information systems [3]. From a control standpoint, the system accurately characterizes the performance and behaviour of the static and dynamic mathematical model is a special form of feature model, which is characterized by the model complete content.

Feature model can be divided into two categories: deterministic model and intelligent characteristic model [4]:

(1) The deterministic model. It is mainly for those with high order complex mathematical equations describing the physical mechanism of clear. This kind of system is generally available lower order time-varying differential equations describing the form feature model.

(2) Intelligent characteristic model. Smart features complex object model is mainly aimed at those not currently using explicit mathematical equation, and with uncertainties. Clear but difficult to describe kinetic equation object from the object physical mechanism for those accused of starting a physical mechanism, establish a direct relationship between the characteristics of input and output control between the characteristic parameters of the model established by empirical research and expert object physical mechanism [4]. In addition, you can also other types of feature models, neural network identification model. Adaptive control structure based on characteristic model can be represented in Figure 1.
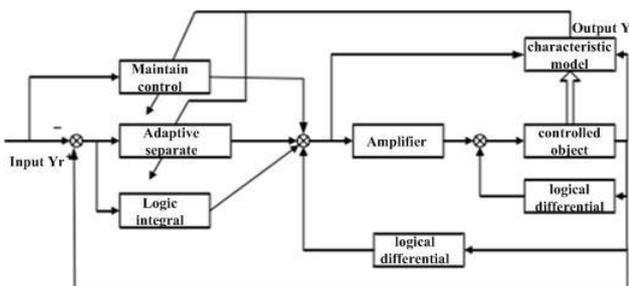

FIGURE 1 Adaptive control structure based on characteristic model

2.2 CREATE THE CHARACTERISTICS MODEL

Generally, when the unique characteristics of the model for its slow deterioration of equation. At present, the linear time-invariant systems feature modelling problem has been solved [5], for some special kind of linear time-varying systems, nonlinear systems, and multiple linear time-varying systems [6, 7], has also been proven that they can use features of the model deterioration or differential equations of second order equations when expressed. These features are derived in many models have been described in detail in the literature, this article only direct quote conclusions as needed. Some features of the model for single-input single-output systems have

proven to be represented by the formula (1) as shown in the second-order differential equation.

$$
\begin{aligned}
m(u+1) = f_1(u)m(u) + f_2 u(u-1) \\
+ g_1(u)x(u) + g_2 x(u-1)
\end{aligned}
, \qquad (1)
$$

where $m(u)$ is output, $x(u)$ is the amount of control, the equation is a characteristic parameter f_1, f_2, g_1, g_2, and the scope thereof can be determined in advance.

When the object is a minimum-phase system, or some non-minimum phase system, in order to simplify the engineering convenience, characterized model can also be used instead of the following form

$$
m(u+1) = f_1(u)m(u) + f_2 u(u-1) + g_1(u)x(u) . \qquad (2)
$$

For some multiple-input multiple-output system, characterized by second-order differential mode has proven to be used as output decoupling type equations expressed

$$
\begin{aligned}
U(u+1) = \tilde{F}_1(u)U(u) + \tilde{F}_2(u)X(u-1) \\
+ \tilde{G}_1(u)X(k) + \tilde{G}_2(u)X(u-1)
\end{aligned}
. \qquad (3)
$$

Set the desired output is $U_r(u)$, the actual output is $\tilde{U}(u)$, the control amount of $X(u)$, $\tilde{F}_1(u)$, $\tilde{F}_2(u)$, $\tilde{G}_1(u)$, $\tilde{G}_2(u)$ is a characteristic parameter estimates. Identification of characteristic parameters shown by (4) Feature Model

$$
\begin{aligned}
u(k+1) = f_1(k)u(k) + f_2(k)u(k-1) + g_1(k)x(k) \\
= \Phi^T(k-1)\theta(k)
\end{aligned}
, \qquad (4)
$$

where
$$
\Phi(k-1) = \begin{bmatrix} u(k-1) & u(k-2) & x(k-1) \end{bmatrix}^T
$$
$$
\theta(k) \begin{bmatrix} f_1(k) & f_2(k) & g_1(k) \end{bmatrix}^T
$$

In order to achieve adaptive control, you must select the appropriate line identification method to estimate the parameters of f_1, f_2, g_1. Many online identification methods available, each method has its own characteristics, and total factor when combined with adaptive control when there is a question of the applicability. Applicability refers to the so-called identification accuracy, convergence speed computation, memory footprint, and in conjunction with the controller after effects can meet the performance requirements.

2.3 RELIABILITY CONTROL MODEL BASED ON PETRI NETS

Petri net is a kind of network information flow model, including the conditions and events with two types of nodes, in the conditions and events for the nodes of the two graphs and state information representing tokens distribution, and triggered rules of the event driven state evolution according to certain, which reflects the dynamic operation process of the system. Under normal circumstances, described the event nodes with small rectangular, called change; described the Condition node with a small circle, called the library [8]. Not between two nodes and two base nodes have directed arc is connected, and between nodes and base nodes can have directed arc connecting, which made up of two sub graph is called network. Some of the library network node on the number of dots tokens, which Petri network. This paper proposes a control algorithm based on fuzzy neural Petri net, the algorithm is described as follows:

A fuzzy neural Petri net is defined as nine tuple:
$FNPN = (P,T,F,C,W,\mu,\alpha,\beta,M)$, where

$P = \{p_1, p_2, ..., p_m\}$ library is a finite set of the total;

$T = \{t_1, t_2, ..., t_n\}$ is a finite set of changes;

$F \subseteq (P \times T) \cup (T \times P)$ is a finite set of arcs total;

$C = \{X, Y, G\}$ is a set of propositions, wherein,

$X = \{x_1, x_2, ..., x_n\}$ is the input proposition,

$Y = \{y_1, y_2, ..., y_m\}$ intermediate proposition,

$G = \{g_1, g_2, ..., g_k\}$ is the conclusion proposition ;

$W = \{w_1, w_2, ..., w_n\}$ is the input arc on the right set of values;

$\mu = \{\mu_1, \mu_2, ..., \mu_n\}$ is a finite set of fuzzy trust degree;

$\alpha = P \to C$ is the place to proposition mapping;

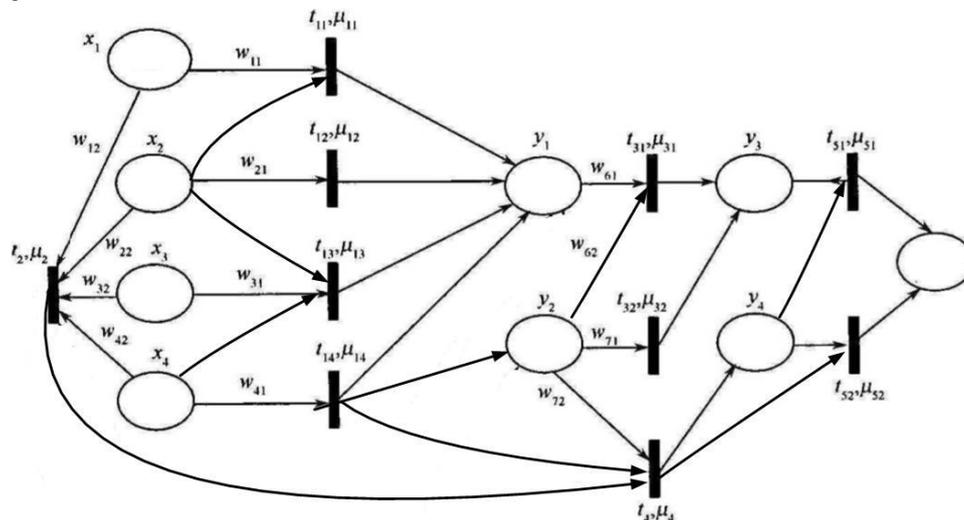$M = P \to [0,1]$ is a mapping. Figure 2 shows the reliability of the model based on Petri nets.

FIGURE 2 Reliability of the model based on Petri nets

For system reliability analysis of Petri network model, based on the 2/3 system as an example, assume that each component is equipped with a device, the reliability of the mock-up system analysis of Petri net model as shown in figure 3, Wherein p_1, p_2, p_3 denote the three components in a good state, as long as these three libraries library has two tokens, the system can work, there are tokens with p_{sc} indicates that the system is in good condition; p_{1f}, p_{2f}, p_{3f} are respectively the three members in the running state, the same library as long as these three libraries have two tokens, then the system is in the failure state; There are token representation with p_{sf} system failure; changes t_{1f}, t_{2f}, t_{3f} denote failure process three members, with a time characteristic, therefore, represented by a rectangular frame; similarly, changes of t_{1r}, t_{2r}, t_{3r}, respectively, during the operation of the three members; The other six changes are immediately change, change that as long as there are tokens in the input library and the corresponding input arc suppression library no token, the changes triggered immediately.
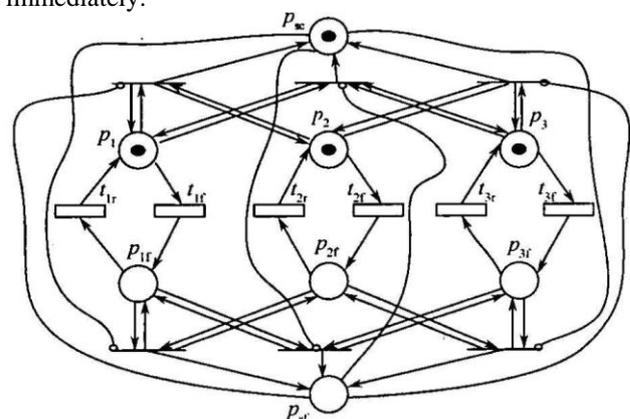

FIGURE 3 Reliability of the mock-up system analysis of Petri net model

2.4 RELIABILITY MODELLING BASED ON NEURAL NETWORKS

Neural networks are an important part of intelligent control, it has to learn, adapt, self-organization, arbitrary function approximation and massively parallel processing capabilities, particularly suitable for nonlinear control systems and uncertainty of the system. Involved in a wide range of neural network control, the paper selected for analysis only two typical networks. Figure 4 shows the single neuron adaptive control structure diagram. Single neuron adaptive controller control algorithm is as follows:
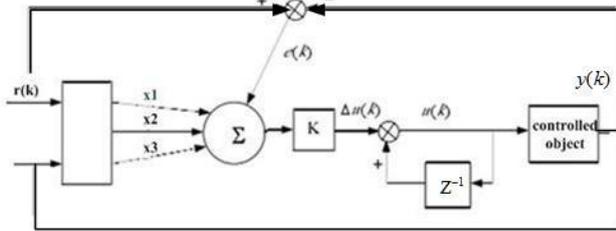

FIGURE 4 Instance of data fusion

$$x(k) = x(k-1) + K\sum_{i=1}^{3} w_i(k)u_i(k) , \qquad (5)$$

where K is a proportional coefficient of neurons, $K > 0$, $w_i(k)$ is the weight coefficient, $i = 1, 2, 3$. The controller is achieved by adjusting the weighting coefficients adaptive network, self-organizing features, the use of a learning rule to adjust the weights supervision, while adding items into supervised learning algorithm $z(k)$, then the weights of the neural network learning algorithm can be used to represent the formula (6):

$$
\begin{aligned}
w_1(i) &= w_1(i-1) + \eta z(i)x(i)u_1(i) \\
w_2(i) &= w_2(i-1) + \eta z(i)x(i)u_2(i) , \\
w_3(i) &= w_3(i-1) + \eta z(i)x(i)u_3(i)
\end{aligned}
\qquad (6)
$$

$$
\begin{aligned}
x(k) &= x(k-1) + K\sum_{i=1}^{3} w_i(k)u_i(k) \\
&= x(k-1) + Kw_1(k)z(k) + Kw_2\left[z(k) - e(k-1)\right]. \\
&+ Kw_3(k)[z(k) - z(k-2)]
\end{aligned}
\qquad (7)
$$

Observation equation (5) to (7) shows that the single neuron self-selection using the controller performance and K values have a great relationship. Petri nets and its role in controlling the proportion of adjustable parameters similar response when the system is slow, by increasing K, faster response times, but K is too large, it will produce a large amount of overshoot, and may even make the system does not stable.

3 Simulation and performance analysis

In this paper, the reliability of the model shown in Figure 2, for example, the reliability of the application block diagram of a network system of the bridge shown in Figure 5, the edges of the set order of the reliability R_a, R_b, R_c, R_d, R_e, can be obtained by the method of system reliability truth table degrees are:
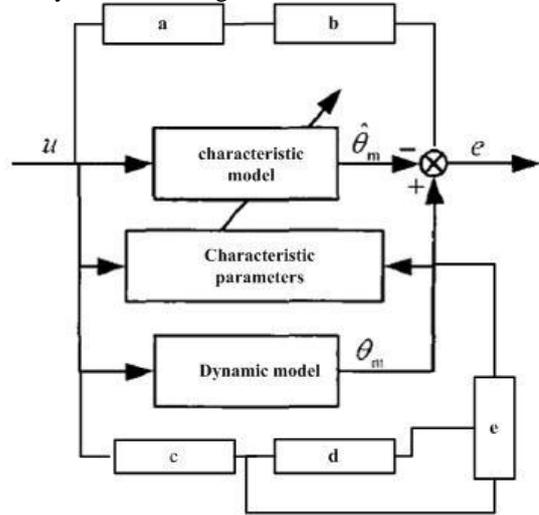

FIGURE 5 Reliability block diagram of the system

$$
\begin{aligned}
R_s &= (1-R_a)(1-R_b)R_c R_d(1-R_e) + \\
&(1-R_a)(1-R_b)R_c R_d R_e(1-R_e)R_b R_c(1-R_d)R_e \\
&+R_a R_b R_c R_d(1-R_e) + R_b R_c R_d R_e \\
&+R_a(1-R_b)(1-R_c)R_d R_e
\end{aligned}
\qquad (8)
$$

Randomly generated 100 groups of component reliability value (0.85~1), the type (8) to calculate the system reliability as the sample value.

The model shown in Figure 2 as the reliability of the reliability of the estimated model bridge system, wherein, $x_1 \sim x_5$ represents successively member a, b, c, d, e reliability of 2.3 with the learning algorithm, using Java programming and a set of initial values are given on the assumption that the expert knowledge of the situation: $\omega_{11} = \omega_{21} = \omega_{31} = \omega_{41} = \omega_{51} = \omega_{61} = \omega_{71} = 0$, $\omega_{12} = \omega_{22} = \omega_{32} = \omega_{42} = \omega_{52} = \omega_{62} = 1$. All were taken to a trust, the step size chosen 0.0001, with 100 sets of sample data values and the trust of the right training, the training results shown in Figure 6.
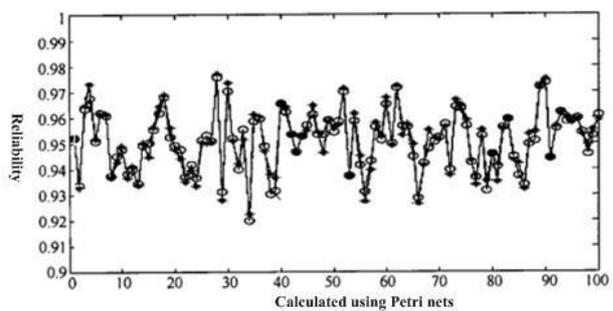

FIGURE 6 The results of training samples

Because the feature model needs to be calculated in the position loop in real time, so the combination of servo system, the sampling period in the process of simulation

for $\Delta t = 10$ms. Because the system is open-loop state, so given the control value should not be too high, the simulation time should not be too long, make the simulation time in $\Delta t = 40$s. The given initial value is:

$$\tilde{\theta}(0) = 10^{-4} \times [1111]^T, P(0) = 10^7 \times I_{5\times5}.$$

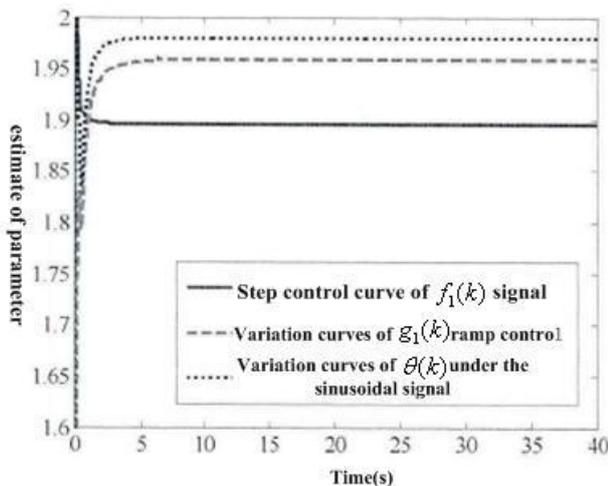The simulation results are shown in figure 7.

FIGURE 7 The curve under the three input control signal

4 Conclusions

Based on the existing research on the basis of characteristics of the model control theory, the amount of features and characteristics of the model are analysed, finishing, introduces the features of the model based on full coefficient adaptive control features, and gives the general design ideas and design steps. Petri nets control study and a number of neural network control is the essence of the model-based control features, the extension of the scope of this theory. Finally, the reliability of the design of the particular track motor control algorithm, the algorithm consists of two parts, the first part is fed inverse dynamics and analytical method are combined to solve the nominal pressure command and gesture commands based on feedback from the learning section Neurons adaptive control to correct the error. Simulation results show that the designed controller has a good track tracking capability.

Acknowledgments

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Authors

Zhang Feng, born on June 26, 1980, in Shannxi Yulin

Current position, grades: associate professor in Yulin University.
University studies: MS degree in Computer science from Xidian University in 2009.
Scientific interest: Cloud integrated manufacturing technology, the modeling of complex systems, the Internet of Things applications.

Xue Hui-feng, born on June 16, 1964, in Shanxi Yuncheng

Current position: professor in Northwestern Polytechnical University
University studies: PhD degree in Water resource economics from Xi'an Polytechnic in 1995
Scientific interest: modelling of complex systems, Simulation and performance evaluation, management, systems engineering, energy and environmental systems engineering, computer control, intelligent control, network control