Article ID:1000 - 8152(2000)03 - 0387 - 06

Multi-Mode Controller Designing Based on Neural Networks *

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Abstract:A method of intelligent multi-mode control is introduced. The scheme is based on the neural networks which integrate multiple modules and controllers of nonlinear time-varying system, and also the neural networks' abilities of qualitative reasoning, quantitative numeric reckoning, learning and memorizing. Combining the qualitative knowledge and quantitative mathematical information of system, the approach provides good control over the nonlinear time-varying system with wide variation of parameters. Finally, we use this method to the control design of laser guidance missile and the result of the simulation shows that the performance is excellent and this approach is sample and easy to realize.

Key words:intelligent control system; neural networks; multi-mode control

Document code:A

基于神经网络的多模态控制器设计

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摘要:基于神经网络所具有的定性推理和定量数值并行计算能力,以及学习记忆能力,集成非线性系统的多个特征模型和控制器,实现了控制系统的多模态智能控制.该方法充分结合系统的定性知识和定量数学描述信息,实现了参数大范围变化时变系统的良好控制.最后用该方法对某型激光制导炸弹设计了一多模态控制器,仿真结果表明了该方法的优良性能.

关键词:智能控制系统;神经网络;多模态控制

1 Introduction

One of the basic ideas of intelligent control system is that controllers determine or alternate the control strategy on-line to achieve satisfying control effect based on qualitative knowledge and accumulated experience of controlled complex plants which are of nonlinearity, time-variance and uncertainty[1]. In other words, the intelligent control systems identify the characteristic of sampling information according to diagnostic model of the system to determine what kind of state the system belongs to at that time, then the controller memorizes it and determines corresponding control strategic decision mode. The so-called control strategic decision is referred to some quantitative and qualitative relation set among control input u, preset characteristic state and characteristic information memorized before. This kind of control strategy which changes continuously is called multi-mode control. Thus, intelligent control systems are mixed control process which is described by non-mathematics generalized world model based on knowledge and mathematics formula model simultaneously[2,3].

In this paper, multi-characteristic models are constructed by using the structure and the parameters of the system and corresponding multi-groovy controllers are designed. Neural networks are used to integrate thus multi-characteristic models and controllers so that the multi-mode control of the system is realized. The ability of this controller stabilizing a class nonlinear time-varying system is analyzed in this paper. Then based on the analysis of the stability of the controller, neural networks are used to integrate multi-characteristic models and controllers of the system to realize the multi-mode control. At last, multi-mode controller is designed for a certain type of laser guide missiles and the simulations are given.

* Foundation item: supported by the National Natural Science Foundation of China(69904004).
Received date:1998 - 09 - 17; Revised date:1999 - 11 - 22.

2 Property analysis of controller for a class of nonlinear time-varying system

When the controlled plant is time-varying, the stability of the controller designed based on nominal model has this conclusion as follows:

Lemma 1 Given positive matrix M represented as $M > 0$, and non-positive matrix N represented as $N \leqslant 0$, then $MN \leqslant 0$, $N^{\mathrm{T}}M \leqslant 0$.

Lemma 2[5] For nonlinear time-varying system

$$\dot{x} = f(x, t). \tag{1}$$

Assumed that

$$f(0, t) = 0, \tag{2}$$

$f(x, t)$ is belong to C^1 for x, define

$$A(t) = \left[\frac{\partial f(x,t)}{\partial x}\right]_{x=0}, \tag{3}$$

$$\Psi(x,t) = f(x,t) - A(t)x. \tag{4}$$

If there is

$$\lim_{\|x\| > 0}\sup_{t>0} \frac{\|\Psi(x,t)\|}{\|x\|} = 0, \tag{5}$$

and $A(t)$ is limited, that is

$$A(t) < \infty, \ \forall\, t \geqslant 0 \tag{6}$$

then, when linear system

$$\dot{z}(t) = A(t)z(t) \tag{7}$$

is coincident asymptotically stable for equilibrium in time interval $[0, \infty]$, then the original nonlinear system (1) is also coincident asymptotically stable for equilibrium in time interval $[0, \infty]$. The system (1) is called structure stable nonlinear time-varying system.

Define autonomous nonlinear system as:

$$\dot{x} = \tilde{f}(x). \tag{8}$$

Theorem 1 If controller $H(x)$ can asymptotically stabilize the structure stable nonlinear autonomous system (8) in $x \in \Omega$, $\Omega \subset \mathbb{R}^{nX1}$, namely system Σ

$$\Sigma: \quad \dot{x} = \tilde{f}(x) + H(x) \tag{9}$$

is asymptotically stable, then the controller $H(x)$ can stabilize system $\tilde{\Sigma}$

$$\tilde{\Sigma}: \quad \dot{x} = f(x,t) + H(x). \tag{10}$$

Where

$$f(x,t) = \tilde{f}(x) + \Delta f(x,t). \tag{11}$$

Here $\Delta f(x,t)$ satisfies that the nonlinear system $\dot{x} = \Delta f(x,t)$ constructed by $\Delta f(x,t)$ is structure stable nonlinear time-varying system and is asymptotically stable.

Proof Known that system Σ is asymptotically stable, construct Lyapunov function

$$V = x^{\mathrm{T}}Qx. \tag{12}$$

thene exists a positive matrix Q^*, such that

$$\dot{V} = \dot{x}^{\mathrm{T}}Q^*x + x^{\mathrm{T}}Q^*\dot{x} = \\ [\tilde{f}(x) + H(x)]^{\mathrm{T}}Q^*x + x^{\mathrm{T}}Q^*[\tilde{f}(x) + H(x)] < 0. \tag{13}$$

For system $\tilde{\Sigma}$, Lyapunov function constructed as

$$\tilde{V} = x^{\mathrm{T}}Q^*x. \tag{14}$$

Q^* is as above, we have

$$\dot{\tilde{V}} = \dot{x}^{\mathrm{T}}Q^*x + x^{\mathrm{T}}Q^*\dot{x} = \\ [f(x,t) + H(x)]^{\mathrm{T}}Q^*x + x^{\mathrm{T}}Q^*[f(x,t) + H(x)]. \tag{15}$$

Substituting (11) into (15)

$$\begin{aligned}\dot{\tilde{V}} = {} & [\tilde{f}(x) + \Delta f(x,t) + H(x)]^{\mathrm{T}}Q^*x + \\ & x^{\mathrm{T}}Q^*[\tilde{f}(x) + \Delta f(x,t) + H(x)] = \\ & \tilde{f}(x)^{\mathrm{T}}Q^*x + x^{\mathrm{T}}Q^*\tilde{f}(x) + H(x)^{\mathrm{T}}Q^*x + \\ & x^{\mathrm{T}}Q^*H(x) + \Delta f(x,t)^{\mathrm{T}}Q^*x + x^{\mathrm{T}}Q^*\Delta f(x,t) = \\ & \dot{V} + \Delta f(x,t)^{\mathrm{T}}Q^*x + x^{\mathrm{T}}Q^*\Delta f(x,t).\end{aligned}$$

In addition, because $\dot{x} = \Delta f(x,t)$ is structure stable nonlinear system and is asymptotically stable, the assumption can be made that $\Delta f(x,t) = A(t)x + \Phi(x,t)$, according to lemmas

$$A(t) = \left[\frac{\partial \Delta f(x,t)}{\partial x}\right]_{x=0}, \tag{16}$$

$$\Phi(x,t) = \Delta f(x,t) - A(t)x, \tag{17}$$

$$\lim_{\|x\| \to 0} \frac{\|\Phi(x,t)\|}{\|x\|} = 0. \tag{18}$$

Then

$$\begin{aligned}& \Delta f(x,t)^{\mathrm{T}}Q^*x + x^{\mathrm{T}}Q^*\Delta f(x,t) = \\ & x^{\mathrm{T}}(A(t)^{\mathrm{T}}Q^* + Q^*A(t))x + \\ & \Phi(x,t)^{\mathrm{T}}Q^*x + x^{\mathrm{T}}Q^*\Phi(x,t) = \\ & -x^{\mathrm{T}}W(t)x + 2\Phi(x,t)^{\mathrm{T}}Q^*x,\end{aligned} \tag{19}$$

where $W(t)$ is a positive matrix, because $\Phi(x,t)$ satisfies Eq. (18), a positive number r can be selected, s.t. When $\|x\| < r$,

$$\|\Phi(x,t)\| \leqslant \frac{1}{3}\frac{\|W(t)\|}{\|Q^*\|}\|x\| \tag{20}$$

is held, substituting $2\Phi(x,t)^{\mathrm{T}}Q^*x$ into (20), we obtain

$$|2\Phi(x)^{\mathrm{T}}Q^*x| \leqslant \frac{2}{3}x^{\mathrm{T}}W(t)x. \tag{21}$$

Then, Eq. (19) can be rewritten as

$$\Delta f(x,t)^{\mathrm{T}}Q^*x + x^{\mathrm{T}}Q^*\Delta f(x,t) = -\frac{1}{3}x^{\mathrm{T}}W(t)x < 0. \tag{22}$$

For $\dot{V} < 0$ is known, so

$$\dot{\tilde{V}} = \dot{V} + \Delta f(x,t)^{\mathrm{T}} Q^{*} x + x^{\mathrm{T}} Q^{*} \Delta f(x,t) < 0. \tag{23}$$

System $\tilde{\Sigma}$ is asymptotically stable.

3 Multi-mode controller

The purpose of designing the control system by using integrated model is to construct simple and perfect multi-characteristic models of system to describe and reflect sufficiently the characteristics of the real system, after that, to design multi-controllers with good property according to multi-characteristic models and to switch among these multi-controllers according to the relationship among control input u, nonce characteristic states and characteristic information memorized before in order to change the control strategy and to realize the multi-mode control. It is a challenging problem to integrate this multi-characteristic models and corresponding multiple controllers.

The neural network control is a multi-mode control method combining qualitative control and quantitative control[2,6]. From the perspective of information mapping, it is a single mapping function relation between control input and output of general controller. However, the neural network control system is a multi-mapping function relation, which can learn, memory and realize the function of several general controllers. In practical control system, neural network controller can first determine in what kind of function area of controller the system locate according to the control input u, nonce characteristic states and characteristic information memorized before. After that, corresponding control strategy is given to realize the smooth switching among multiple controllers. In practice, the qualitative reasoning and quantitative control of neural networks are carried on simultanously, which is determined by the inner structure and knowledge memory style of neural networks[7].

The concrete design process is described as follows:

1) Divide the parameter disturbance area $\Delta\theta \in \Omega$ as multiple regions. In every region, a working point is selected and based on this point the controlled plant model is determined. Assume that the disturbance area is divided into n regions and n models are obtained. Design n general controllers according to certain property for n models of system using known control methods. There are n allowed disturbance areas as $\delta_i (i = 1,2,\cdots,n)$ according to the analysis in the last section. If $\hat{\Omega} = \delta_1 \cup \delta_2 \cup \cdots \cup \delta_n \supseteq \Omega$, then n controllers can stabilize the system robustly in the disturbance area $\Delta\theta \in \Omega$.

2) Get the normal control data of n models of system (based on n working point) through testing in the site or simulation, namely, the control inputs and control outputs data pair sequence $\{\mathrm{in}_i(t), \mathrm{out}_i(t)\}$ $(i = 1,2,\cdots,n)$ corresponding n controllers. These data pairs contain not only the information of n controllers but also the information of n-characteristic models.

3) Construct the "demonstration space" to train neural networks using n data pair sequences $\{\mathrm{in}_i(t), \mathrm{out}_i(t)\}$ $(i = 1,2,\cdots,n)$. The model structure of the neural networks parallels that of general controllers. In other words, if the control realization of general controller is input-output static mapping, the neural network model can use static BP networks or cerebella model coupling networks; if the general controller is a dynamic link, dynamic networks——recurrent neural networks can be used.

4) If the requirement of network learning error is satisfied, this neural network controller can be used to achieve good control effect in the disturbance area $\Delta\theta \in \Omega$ of parameter θ. According to the analysis described above, under the condition of satisfying the theorem, neural network controller is of the equivalent function with that of multiple general controller in the "demonstration space". That is, if multiple general controller can achieve good control effect in $\Delta\theta \in \Omega$, the neural network controller can do as well in the same condition.

Whether neural networks can learn and memorize multiple general controllers is the approaching ability of the neural networks and the generalizing ability of the neural networks (the ability of inner interpolating and extrapolating) which have been argued in many references. Three-layer BP networks can approach arbitrarily any nonlinear function in L^2 space, Li offered the proof in 1992 that dynanic neural networks——Elman networks can approach globally arbitrary differential trajectory if they have enough nodes, that is, they can extract dynamic characteristics of any time-varying information[8].

In the following section, this method is used in the control of laser guided missile. The simulation will demonstrate that this method has good control performance.

4 Multi-mode controller design for the roll channel of laser guided missile

Guided aeronautic missiles are a kind of precisely guided weapon thrown in the air. In general condition, the controlled plant is very complex and high-order with unmodelled dynamic and large-scale and time-varying fast parameters caused by the height the missile located, time-varying character of velocity and nonlinearity of the derivative of air dynamics in the missile thrown process. Hence, there is a higher requirement for controller property in designing the system. It is difficult to guarantee the satisfying flying performance under all kinds of flying conditions of missile using general fixed constant parameter controller.

In the control system design of guided missiles, it is very important to control the roll angle along the lengthways axes of missiles (roll control channel). The crosswise rolling of missile can cause not only the coupling among pitch channel, yaw channel and roll channel but also the declining of the guiding precision.

The mathematics model of roll channel of guided missile can be described as

$$\dot{X} = A(H,V)X + b(H,V)u. \tag{24}$$

That is

$$\begin{bmatrix}\dot{\gamma}\\ \ddot{\gamma}\\ \dddot{\gamma}\end{bmatrix} = \begin{bmatrix}0 & 1 & 0\\ 0 & 0 & 1\\ 0 & a_1(H,V) & a_2(H,V)\end{bmatrix}\begin{bmatrix}\gamma\\ \dot{\gamma}\\ \ddot{\gamma}\end{bmatrix} + \begin{bmatrix}0\\ 0\\ b(H,V)\end{bmatrix}u. \tag{25}$$

Where, γ is the roll angle of missile, u is the control input, H, V is the height and velocity of missile respectively. Since the variance of H, V is in certain area, all varying parameters are limited:

$$\begin{cases} a_{i\max} \geqslant a_i(H,V) \geqslant a_{i\min},\ a_i(H,V) \neq 0, i = 1,2, \\ b_{\max} \geqslant b(H,V) \geqslant b_{\min},\ b(H,V) \neq 0. \end{cases} \tag{26}$$

Then we can conclude that system $[A(H,V), B(H,V)]$ is controllable.

Some laser guided missile works between maximal air pressure ($h = 500$ m, $v = 300$ m/s) and minimal air pressure ($h = 6000$ m, $v = 200$ m/s).

According to the above analysis of designing process, we select three working points as:

Working point 1: $h = 6000$ m, $v = 200$ m/s,

Working point 2: $h = 3000$ m, $v = 250$ m/s,

Working point 3: $h = 500$ m, $v = 300$ m/s.

According to the characteritics of missile in three points, three controlled plant models can be achieved. For these three models, the corresponding three controllers are designed by using state feedback method under certain performance index. The control input and output of these controllers are sampled to get their dynamic character information. The neural networks controller synthesizes the dynamic character information of these three controllers by learning and has the function of the three controllers, then the neural network controller can be used to control the missile.

Using neural network controller to control the laser guided missile at three working points respectively and with 10 degree initial roll maladjusted angle. The simulations of roll angle $r(t)$ of missile, deflection angle $y(t)$ of helm are given as Fig.1 and Fig.2.

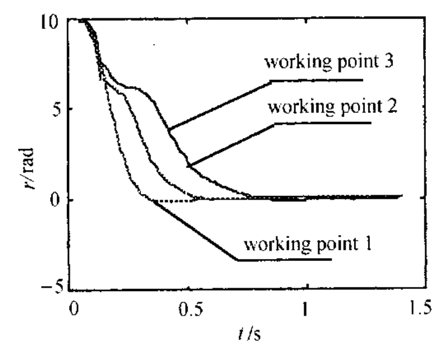

Fig.1 Roll angles of missile at three working points

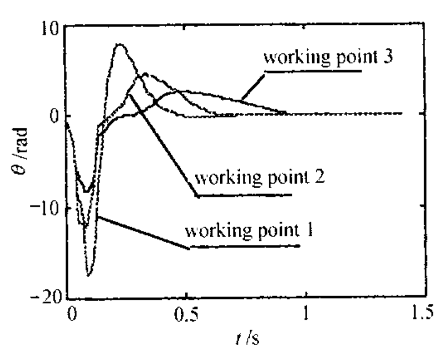

Fig.2 Deflection angles of helm at three working points

From the simulations we can see that the neural network controller has good performance which can adjust roll maladjusted angle of missile to zero within 1 second not only in maximal air pressure or in minimal air pressure but also at the working point 2 and there is nearly no overshot in dynamic process.

In order to verify the control performance of neural networks controller in other conditions, the simulations in the conditions of (h = 5000 m, v = 215 m/s), (h = 4000 m, v = 240 m/s), (h = 2000 m, v = 270 m/s), (h = 1000 m, v = 285 m/s) are given as Fig.3 and Fig.4

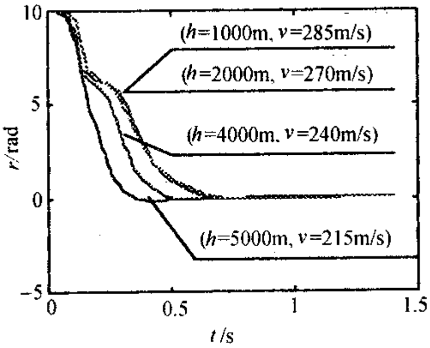

Fig.3 roll angles of missile at above working points

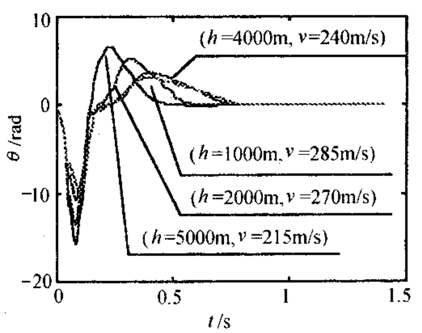

Fig.4 Deflection angles of helm at above workin points

In order to compare the control performance of neural network multi-mode controller with the other controller (such as variable structure controller), the inputs of helm of the two kinds of controllers in maximal and minimal air pressure are given as Fig.5 and Fig.6. It is shown that in the missile control variable structure control can guarantee good performance of the system at different height, different air velocity and different air dynamic character conditions. But there exits chattering in variable structure control which has become the main problem to undermine its applications.

From the above simulations, we can see that neural network controller maintains the same good performance as that of variable structure controller. Moreover, it overcomes the inherent drawback of variable structure control fundamentally——chattering problem.

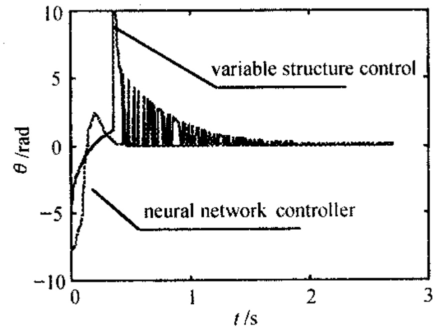

Fig.5 Input of helm in minimal air pressure

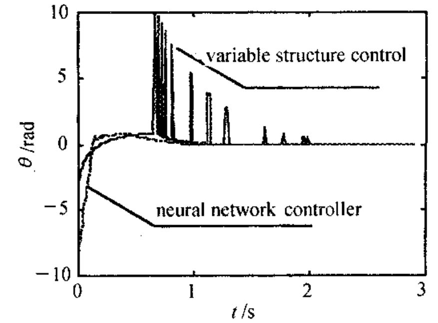

Fig.6 Input of helm in maximal air pressure

5 Conclusion

In this paper, based on the analysis that the general controllers and neural network controller realized by learning have the equivalent function, multiple characteristics models of system are integrated and the qualitative knowledge and quantitative mathematical information of system are combined adequately to realize the multi-mode control of the system. Finally, we apply this method to the control design of laser guidance missile and the result of the simulation shows that it performs excellently.

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