The Joint Control of the Spacecraft Return Capsule's Temperature and Humidity

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Abstract. This paper mainly for the joint control methods of the spacecraft return Capsule's temperature and humidity have been studied. According to the characteristics of temperature and humidity, it designs the object model of the temperature and humidity, and designs the model of decoupling controller on the basis of temperature and humidity model. Using a PID controller based on CMAC neural network and Smith Predictor Controller approaches to design the complex controllers. Using the toolbox of MATLAB software simulates the control system, and changes the interference parameters. The simulation shows that the composite controller has the flexibility and adaptability of the CMAC neural network, but also has high accuracy of PID controller, and its control is robust and good control effect.

1 Introduction

The development of spacecraft has important significance for human life, national economy and the scientific and technology. And it has become an important indicator of the future international competitiveness. The thermal radiation of the space environment is very different from the ground environment. In order to ensure the structure of the spacecraft, the safety of the instrument and the astronauts can have a comfortable working and living space, the thermal comfort control is needed. Therefore, the control system of the spacecraft temperature and humidity is an indispensable part of the spacecraft protection system, and a good temperature and humidity control system is necessary to ensure the normal operation of the spacecraft and appropriate working conditions.

2 Joint Control System Model

In the joint control system of temperature and humidity of the spacecraft, we can use the empirical modeling method and use the time varying delay model for the controlled object temperature and humidity module. Temperature and humidity are two highly coupled variables, and they must be decoupled to implement effective control. From the practice experience, the temperature variable has a great influence on the humidity, while the humidity has little effect on the temperature. The block diagram of the joint control system of temperature and humidity of the spacecraft is shown in Fig. 1.

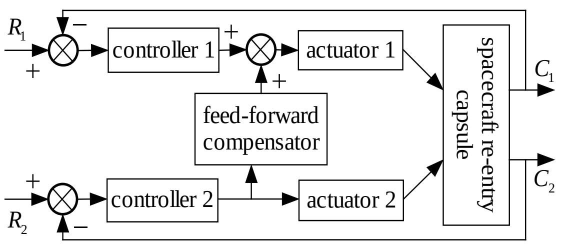

Fig. 1 The joint control system block diagram of temperature and humidity

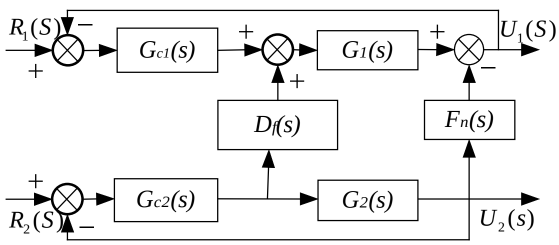

Fig. 2 The joint control system block diagram based on feed-forward compensation

Where the controlled object module of the humidity control system is the humidification valve and the blower, and the transfer function can be used in the first order delay model:

$$G_1(s)=\frac{K_1e^{-\tau_1 s}}{(TS+1)} \ , \ \tau_1 = NT \ . \quad (1)$$

The controlled object module of the humidity control system is heating valve and cooling valve, and the transfer function can be used in the second order lag model:

$$G_2(s)=\frac{K_2e^{-\tau_2 s}}{(T_1S+1)(T_2S+1)} , \ \tau_2 = NT \ . \quad (2)$$

In this paper, the coupling transfer function of temperature to humidity is $F_n(s)=1$.

Fig. 2 is the joint control system block diagram of temperature and humidity based on feed-forward compensation decoupling. Where the transfer function of controlled object module of the humidity control system is $G_1(s)$, the transfer function of controlled object module of the temperature control system is $G_2(s)$ and the interference transfer function of temperature module to humidity module is $F_n(s)$. The transfer function of controller 1 is $G_{c1}(s)$, the transfer function of controller 2 is $G_{c2}(s)$ and the transfer function of the feed-forward controller is $D_f(s)$. According to the principle of feed-forward control, it can be got:

$D_f(s)G_1(s)-G_2(s)F_n(s)$=0, that is $D_f(s)=G_2(s)F_n(s)/G_1(s)$. (3)

3 Joint Control System Controller Design

3.1 Smith Predictor

Smith prediction method is also called pure hysteresis compensation method. The goal of the design is to introduce a pure lag link. The temperature control system and humidity control system based on Smith predictor can effectively overcome the influence of large pure delay process on the stability and dynamic performance of the control system, and the realization process is simple, the reliability is good, and the performance index of the closed-loop control system can achieve the best.

The working principle is simplify the dynamic characteristics of the controlled object under the action of the basic disturbance into mathematical model of in-tandem model of a pure delay and a first order inertia link or a two order inertia link. According to the mathematical model of the input, the predictor is used to estimate the possible influence of the control method action on the controlled variable. Instead of having to wait until the controlled amount is reflected, it is beneficial to improve the dynamic performance of the control system. The structure of the Smith predictor is shown in Fig 3.

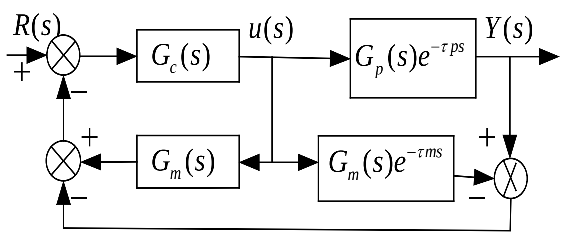

Fig. 3 Smith predictor structure diagram

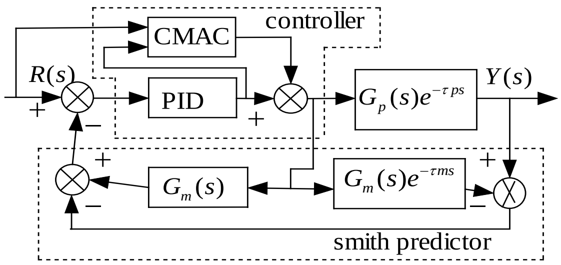

Fig .4 Composite controller block diagram

$G_c(s)$ is the transfer function of controller and $G_p(s)e^{-\tau_p s}$ is the transfer function of controlled object. According to the principle of Smith predictor compensation, there are:

$$G_m(s) = G_P(s) \quad (4)$$

$$e^{-\tau_m s} = e^{-\tau_p s} \quad (5)$$

3.2 CMAC Neural Network

CMAC is an important component of a kind of associative memory neural network, which can learn any number of nonlinear mappings. And it can also be used effectively for nonlinear function approximation, dynamic modeling and control system design. The superior performance of CMAC makes it better than the general neural network with better nonlinear approximation ability, and it is more suitable for nonlinear real-time control under complex dynamic environment.

CMAC neural network treat the input state of the system as a pointer, and stores the related information into a set of memory cells. The CMAC neural network control algorithm:

$$u_n(k) = \sum_{i=1}^{c} \alpha_i \omega_i \tag{6}$$

$$u(k) = u_n(k) + u_p(k) \tag{7}$$

Where, ω is binary selection vector and the initial value is 0. α is the inertia amount and the range of values is 0~1. c is the generalization parameter of CMAC neural network and $u_p(k)$ is the output of PID controller. CAMC adjustment index algorithm:

$$e(k) = \frac{1}{2}(u(k) - u_n(k))^2 \frac{\alpha_i}{c} \tag{8}$$

$$\Delta\omega(k) = \eta \frac{u(k) - u_n(k)}{c} \alpha_i \tag{9}$$

$$\omega(k) = \omega(k-1) + \Delta\omega(k) + \alpha(\omega(k) - \omega(k-1)) \tag{10}$$

Where, η is the learning rate and its range of values is 0~1.

3.3 Composite Controller

As the control object is a pure delay system, the Smith predictor is used to improve the stability of the system. The stability of the system can be greatly improved after the Smith predictor is used in the time varying delay system. The dynamic performance of the control system is difficult to be improved by using the traditional PID controller, and the parameters of the controller are difficult to achieve self tuning, so the CMAC and PID parallel composite control method is adopted. The composite controller block diagram is shown in Fig. 4.

4 System Simulation Analysis

Take: The input signal of humidity control system is $R(s)$=25, the input signal of temperature control system is $R(s)$=25, the humidity control system's interference input signal is $f_1(s)$=0 and the temperature control system's interference input signal is $f_2(s)$=0.

The PID control parameters of humidity control system are P=0.5, I=0.5 and D=0.1, and the PID control parameters of temperature control system are same to humidity control system.

The parameters of the CMAC neural network of the humidity control system are α =0.04, η =0.01, c =5, N =100 and the initial value of ω is 0. The parameters of the CMAC neural network of the temperature control system are same to humidity control system.

4.1 Performance Analysis of Humidity Control System

(1) Analysis of steady state performance. The humidity control model parameters are $T=1$, $\tau_1=1$ and the temperature control model parameters are $K_2=1, T_1=1, T_2=1, \tau_2=1$. Change the humidity control model parameter K_1, and the simulation results of humidity control system are obtained as shown in Fig.5, Fig.6 and Fig.7.

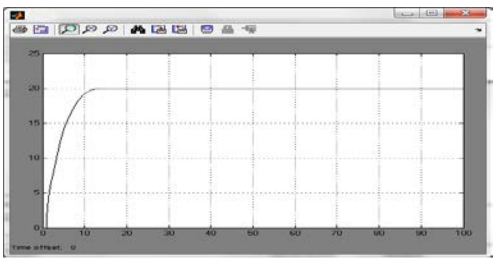

Fig.5. $K_1=1$, Simulation results

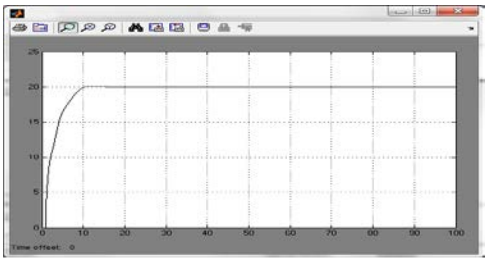

Fig.6. $K_1=2$, Simulation results

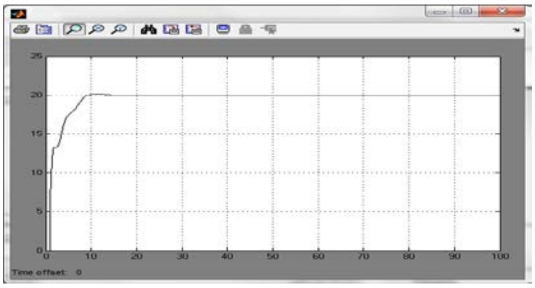

Fig.7. $K_1 = 5$, Simulation results

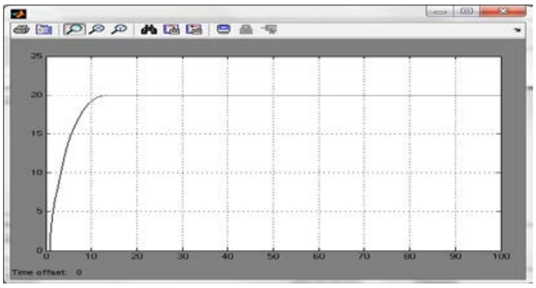

Fig.8. $\tau_1 = 1$, Simulation results

As shown in Fig.5, Fig.6 and Fig.7, the humidity control system is stable and has no steady state error, and its steady state performance is well.

(2) Analysis of robustness. The humidity control model parameters are $K_1 = 1, T = 1$ and the temperature control model parameters are $K_2 = 1, T_1 = 1, T_2 = 1, \tau_2 = 1$. Change the humidity control model parameter τ_1 , and the simulation results are obtained as shown in Fig.8, Fig.9 and Fig.10.

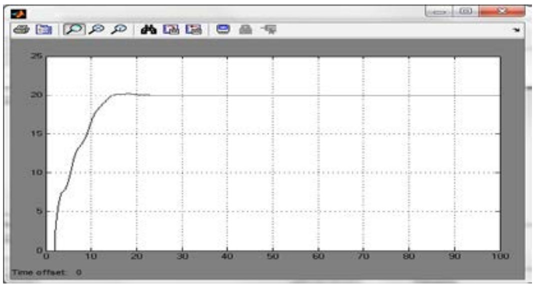

Fig.9. $\tau_1 = 2$,Simulation results

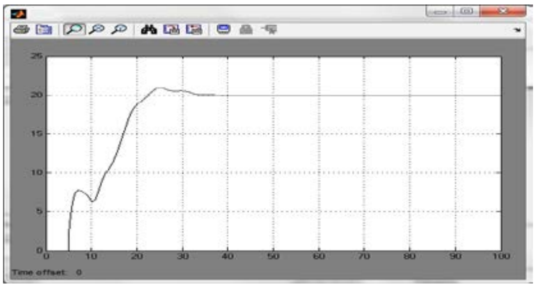

Fig.10. $\tau_1 = 5$,Simulation results

As shown in Fig.8, Fig.9 and Fig.10, the humidity control system is stable, has no steady state error, short rise time, small overshoot, and its robustness is well.

4.2 Performance Analysis of Temperature Control System.

(1) Analysis of steady state performance. The humidity control model parameters are $K_1 = 1$, $T = 1$, $\tau_1 = 1$ and the temperature control model parameters are $T_1 = 1, T_2 = 1, \tau_2 = 1$ .Change the temperature control model parameter K_2 , and the simulation results of temperature control system are obtained as shown in Fig.11, Fig.12 and Fig.13

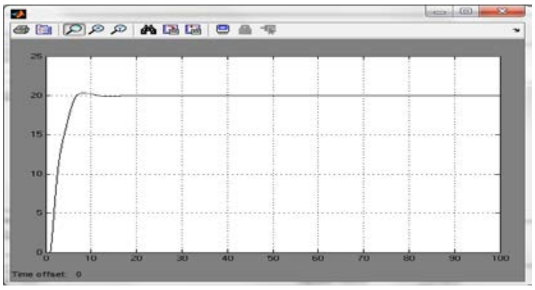

Fig.11. $K_2 = 1$,Simulation results

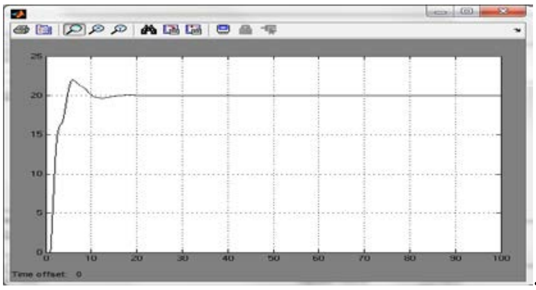

Fig.12. $K_2 = 2$,Simulation results

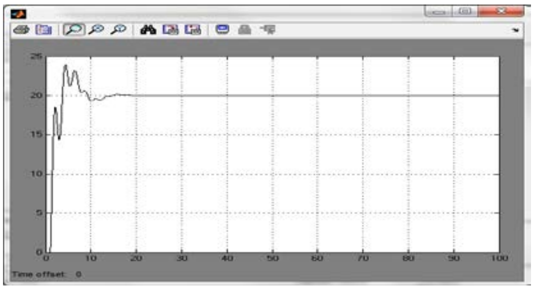

Fig.13 $K_2 = 5$,Simulation results

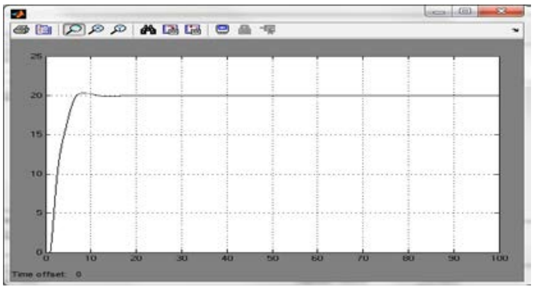

Fig.14 $\tau_2 = 1$,Simulation results

As shown in Fig.11, Fig.12 and Fig.13, the temperature control system is stable and has no steady state error, and its steady state performance is well.

(2) Analysis of robustness. The humidity control model parameters are $K_1 = 1, T = 1, \tau_2 = 1$ and the temperature control model parameters are $K_2 = 1, T_1 = 1, T_2 = 1$. Change the temperature control model parameter τ_2, and the simulation results are obtained as shown in Fig.14, Fig.15 and Fig.16.

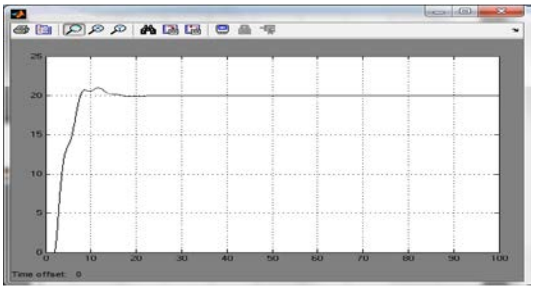

Fig.15 $\tau_2 = 2$, Simulation results

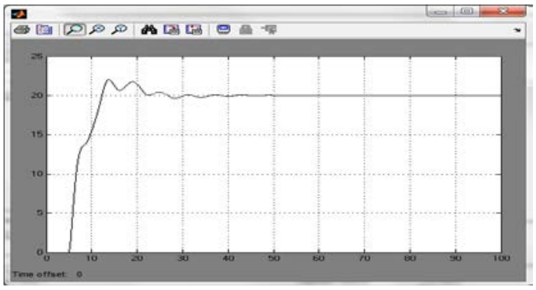

Fig.16 $\tau_2 = 5$, Simulation results

As shown in Fig.14, Fig.15 and Fig.16, the temperature control system is stable, has no steady state error, short rise time, small overshoot, and its robustness is well.

5 Conclusions

In this paper, the method that the PID and Smith predictor composite control based on CMAC neural network is used to design controller. The designed control system achieved the following objectives:

(1) In the steady state performance, the humidity control system and the temperature control system are both stable and have no steady state error, and the steady state performance is well.

(2) In robust performance, the control system is stable, no steady error, short rise time and no overshoot or overshoot when the model parameters of the controlled object humidity and temperature of the composite control system are changed, and it has a strong adaptability and good robustness.

Acknowledgements

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