The simulation of Active Disturbance Rejection Control for
the temperature control in space environment

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Abstract. In order to improve the temperature control effect of nonlinear, large time-delay and inertia space environment simulation equipment, and to solve the contradiction between heating rapidity and overshoot, this paper introduces the Active Disturbance Rejection Control algorithm into space environment simulation temperature control. Based on the platform model, Active Disturbance Rejection Control controller was designed, and the cascade control model of the heat sink gas-nitrogen temperature space environment simulation equipment was established. The cascade control system was simulated on the MATLAB software platform, and the specimen was raised from 0 °C to 100 °C. The step response rise time was about 4000 s. The specimen rise temperature rate is about 1.5° C/min, and the temperature control process is smooth and there is no overshoot. The simulation shows that the Active Disturbance Rejection Control can effectively improve the space environment simulation temperature control effect.

1. INTRODUCTION
In the space environment simulation system, temperature control is a key issue in the whole system. The system requires a wide temperature range, high precision and no overshoot. For nonlinear, large time delay and inertia of the controlled object, control difficulty is further increased. The paper introduces the ADRC into the space environment to simulate temperature control. The algorithm inherits the idea of using the error of the target and the actual output in the PID control to eliminate this error, independents of the object model, to achieve fast, no overshoot and no static control, can solve the heat up the contradiction between quickness and overshoot.

At home and abroad, a lot of research has been done on the ADRC algorithm in the field of temperature control. Ding du Wen of Hunan University of technology applied ADRC cascade control to EFPT experimental device to simulate the temperature control system of industrial electric heating furnace. The system response has a small over and short regulation time, and the temperature stability is ±0.5 [1]. Guang-yuan Ma of Beijing university of aeronautics and astronautics applied the ADRC technology to simulate the temperature control system in high and low temperature environment, and tested the control effect of the system under different working conditions and disturbances. Simulation and test showed that ADRC has the advantages of good dynamic performance, small overshooting and high control accuracy [2]. Bin Liu, Tianjin University of science carried on the temperature control to roaster project of a foundry in Qingdao. He adopted ADRC algorithm, improved tracking differentiator, and combined the hyperbolic tangent function and the inverse sine function as the acceleration function of the tracking differentiator. Through the actual operation results show that the system runs stably and effectively reduce the overshoot, temperature control accuracy in the ± 5 °C. The disturbance caused by the opening of the furnace door can be compensated obviously [3]. Hao
Yang of Shanxi university of science and technology applied ADRC to hot and cold-water mixing system to simulate industrial process system, then studied the control strategy of this kind of coupled time-delay systems. It is confirmed by MATLAB platform simulation that ADRC can effectively decouple control of hot and cold-water mixing. The algorithm could be used to provide reference for complex industrial processes with time-delay coupling properties [4]. Abroad ADRC algorithm is mainly used in some high precision motor control, power converter, vibrating gyro and other fields, which shows the great advantages of this algorithm. This paper verifies the possibility of ADRC in space environment simulation temperature control by simulation.

2. The heat sink gas nitrogen temperature adjustment equipment and mathematical modelling
The gas and nitrogen temperature control equipment can be used to simulate the space environment, and the equipment uses gas nitrogen as the circulating medium. By controlling the temperature of the gas nitrogen by liquid nitrogen refrigeration and electric heater heating, the high temperature or low temperature environment can be accurately obtained, and the fixed-point regulation and control of the temperature of circulating gas-nitrogen within the specified range can be realized [5].

2.1 The composition of the heat sink gas nitrogen temperature adjustment equipment system
The gas-nitrogen temperature-regulating unit mainly includes: gas-nitrogen fan, liquid nitrogen sprinkler, gas-nitrogen heater, control valve, safety valve, gas-nitrogen pipeline system and electronic control system. The system workflow is as follows: First start the nitrogen gas blower, then through the nitrogen sprinkler and the atomized liquid nitrogen to fully exchange heat, obtaining the temperature flow of nitrogen required for the temperature rise and fall of the heat sink, and feeding it into the heat sink and the heat sink wall for heat exchange. After that, the nitrogen from the heat sink outlet returns to the fan inlet for the next cycle.

2.2 Mathematical modelling of heat sink gas nitrogen temperature regulation equipment
By controlling the power of the electric heater, the gas-nitrogen temperature-regulating equipment finally adjusts the temperature of the specimen. The entire process includes heat sink heat exchange, pipe heat exchange, and the radiation process of heat sink to the specimen. The temperature of the specimen is selected as the main controlled parameter, and the nitrogen temperature is the sub-controlled parameter. The output of the main regulator is the given value of the sub regulator. Thus, constitute a set of cascade control system.
Heater ADRC Set Value PI Pipe Heat sink Specimen Specimen temperature Specimen temperature gas nitrogen temperature

Figure 2. The schematic diagram of heat sink gas nitrogen temperature control

The power control model $G_1(S)$ of electric heater and the pipe heat transfer model $G_2(S)$ can be expressed by time delay functions. The internal heat transfer model $G_3(S)$ of heat sink can be expressed as follows:

$$T_s(t + \Delta t) = T_s(t) + \frac{\Delta t}{C_p m s} - \frac{hA}{C_p m s} \left( T_s(t) - T_i(t) \right) + \frac{qA}{C_p m s} \Delta t$$  \hspace{1cm} (Formula 1)

The radiation model $G_4(S)$ of the heat sink on the specimen can be expressed as follows:

$$T(t + \Delta t) = T(t) - \frac{qA}{C_p m} = T(t) - \frac{\varepsilon \sigma A}{C_p m} (T_4(t) - T_s(t)) \Delta t$$ \hspace{1cm} (Formula 2)

Through the above transfer functions, it can be concluded that the regulating object of the main controller is:

$$G_Z = G_1(S) * G_2(S) * G_3(S) * G_4(S) = \frac{127 \times 12}{80 s + 1} \times \left( 35 s + 1 \right) e^{-63 s}$$  \hspace{1cm} (Formula 3)

3. Design of ADRC Controller

ADRC technology is to carry forward the essence of PID control technology and absorb the achievements of modern control theory. ADRC algorithm mainly includes: nonlinear tracking differentiator (TD), extended state observer (ESO), nonlinear error feedback rate (NLSEF) [6].

3.1. The principle of ADRC Controller

The block diagram of ADRC is shown in figure 3 below. The tracking differentiator (TD) arranges the transition process and gives the differential signal of the process. The extended state observer (ESO) gives the object state variable estimate from the object output $y$ and the real-time estimate of the system model internal disturbance and external disturbance synthesis [7]. NLSEF combines the tracking signal and differential signal generated by TD with the state estimation of the system obtained by ESO to properly combine the output control variable $u$ through the nonlinear function.

Figure 3. The basic structure of ADRC controller

3.2 Tracking differentiator (TD)

The principle of the tracking differentiator is to quickly and accurately track the signals acquired by the system and provide the corresponding differential signals [8]. The most commonly used tracking differentiator is the discrete form of the fastest tracking differentiator:

$$f_h = f_h a_n(v_1 - v, v_2, r, h)$$
$$v_1 = v_1 + h v_2$$
$$v_2 = v_2 + h f_h$$  \hspace{1cm} (Formula 4)

In the above formula, $f_h a_n(e, a, r, h)$ is expressed as:
According to the above equation, the differential signal obtained by the tracking differentiator is actually an atypical generalized differential.

3.3 Extended state observer (ESO)

The most important feature of the extended state observer is that it does not depend on the precise disturbance parameters. It will affect all the interfering signals that the system outputs are considered as expansion states and then observe them, so that the control system has an excellent ability to resist external interference [9].

If the controlled object is n-order, its differential equation expression can be written as follows:

\[ x^{(n)} = f(x, x^1, x^2, ..., x^{n-1}, t, w) + bu \]  
(Formula 6)

The corresponding equation of state can be written as:

\[
\begin{align*}
\dot{x}_1 &= x_2 \\
\dot{x}_2 &= x_3 \\
&\vdots \\
\dot{x}_n &= x_{n+1} + bu \\
\dot{x}_{n+1} &= f \\
y &= x_1 
\end{align*}
\]  
(Formula 7)

Then, the extended state \( x_{n+1} \), that is, real-time estimation of \( f \). Thus, the following formula can be obtained:

\[
\begin{align*}
\dot{z}_1 &= z_2 - g_1(z_1 - x_1) \\
\dot{z}_2 &= z_3 - g_2(z_1 - x_1) \\
&\vdots \\
\dot{z}_n &= z_{n+1} - g_n(z_1 - x_1) \\
\dot{z}_{n+1} &= -g_{n+1}(z_1 - x_1) 
\end{align*}
\]  
(Formula 8)

The next step is to select the appropriate \( g_{i, l} \in [1, 2, ..., n+1] \), and take \( x_1 \) as input, thus the following formula can be obtained:

\[ z_1 = x, z_2 \rightarrow z_3 \rightarrow \cdots \rightarrow z_n \rightarrow x^{s-1}, z_{n+1} \rightarrow x^n \]  
(Formula 9)

Even if you don't know the exact value of \( f(x, x^1, x^2, ..., x^{n-1}, t, w) \), you can still get the estimate.

3.4 Nonlinear error feedback control law (NLSEF)

In the closed-loop control system, the error in steady state is the key criterion to measure the stability of the control program. At present, there are two ways to eliminate the steady-state error: one is to introduce integral feedback, which may lead to the problem that the response speed of the controlled system becomes weak; Another method is to increase the inverse K value, which may lead to a large change in the output signal, and then complex nonlinear phenomena appear. For these problems, increase the nonlinear feedback control rate to improve [10], for example, the selected controlled object is of second order, and the state error is expressed by \( \epsilon_1 = e_1 - e_2, \epsilon_2 = e_2 - e_3 \). According to the response output generated by \( e_1 \) and \( e_2 \) as following:

\[
\begin{align*}
u_0 &= \beta_1 e_1 + \beta_2 e_2 \\
u_0 &= \beta_1 fal(e_1, a_1, \delta) + \beta_2 fal(e_2, a_2, \delta), 0 < a_1 < 1 < a_2 \\
u_0 &= -\text{fh}\text{an}(e_1, e_2, r, h_1) 
\end{align*}
\]  
(Formula 10)
In the above formula, the function of \( \text{fal} \) is to attenuate high frequency oscillations. Based on \(|e|^{a}\text{sign}(e)\), it is improved to become a linear and continuous power function near the origin:

\[
\text{fal}(e, \alpha, \delta) = \begin{cases} 
    e^\delta e^\alpha, & |e| \leq \delta \\
    |e|^\alpha \text{sign}(e), & |e| > \delta
\end{cases} \quad \text{(Formula 11)}
\]

4. MATLAB/SIMULINK simulation and analysis

On the MATLAB/SIMULINK software platform, the simulation modelling model (see figure 4) was constructed.

![Figure 4. Simulation model of gas-nitrogen temperature regulation system](image)

According to the above model, the cascade control system is simulated on the MATLAB software platform. The simulation results show that the step response of the specimen from 0 ℃ to 100 ℃ is shown in the figure 5 below. The rising time is about 4000s, and the temperature rise rate of the specimen is about 1.5 ℃/min. The temperature control process is smooth and there is no overshoot.

![Figure 5. The simulation results](image)

5. Conclusion

For the controlled object of nonlinear, large time relay and inertia of the gas-nitrogen temperature regulation equipment for space environment simulation, this method can solve the contradiction between the rapidity of temperature rise and overshoot, maintain the stability of temperature control without overshoot, and has strong anti-interference ability. It is a new control method suitable for engineering applications, and has certain market value.

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