An active disturbances rejection controller based on fuzzy compensator

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Abstract. Digital servo system has a wide application in military equipment. Position controller is one of the important parts in a servo system. Therefore control performance affect system’s capacity directly. The paper introduces an Active Disturbances Rejection Controller (ADRC) based on fuzzy compensator, which uses the fuzzy and active disturbances rejection control technique. Using Tracking Differentiator (TD) to track command signal and feedback signal, transferring them to smooth signal and separating the differentiator signal from them, which are used to build the element of front feed and error control. Fuzzy control technique is used to compensate Extended State Observer (ESO), which decreases variations range of control object. Then increase the estimate precision of extended state observer. An active disturbances rejection controller with perfect control quality is applied in a digital alternating servo system position controller. The results of measurements taken from a laboratory are shown that the proposed controller has an excellent follow precision, good instant response and high output quality. The proposed method solves several difficult problems of servo system position control, such as input signal smoothing, motional disturbance, and hard matching among parameters due to strict requirements on system precision, stability and quick response in position control.

1. Introduction

Active Disturbances Rejection Controller (ADRC) \cite{1-3} is a novel control method advanced by Han Jing-Qing, who is a researcher of Institute of system Chinese Academic of Science. Tracking Differentiator (TD) is used to track command signal and feedback signal. Extended State Observer (ESO) is used to estimate system state, model and disturbance. Nonlinear PID controller (NLPID) is applied to realize nonlinear controller. Active disturbances rejection controller is applied widely in industry control because it has good adaptability, robustness and control quality.

The core of active disturbances rejection Controller is to estimate and compensate the system’s interior and external disturbance by using extended state observer. But the wider variations range of control object, the slower extended state observer estimate time is. The paper \cite{4} gives a method to identify and compensate a part of object model by using an artificial neural-network (ANN). It make the part object model to be known, such that \( f = f_0 + f_1 \), \( f_0 \) is the known part, \( f_1 \) is the unknown part. Then extended state observer just need to observe the unknown part \( f_1 \), which decreases variations range of control object and improve control quality of active disturbances rejection controller.

But the convergence rate of the BP arithmetic in artificial neural-network is slower, and the initial weight selecting has randomness which can’t ensure its convergence to an ideal weight, so off-line identification has to be used.
Fuzzy control is a control strategy which uses the language variable and fuzzy set theory through a mathematics language reduces the operator control. It is not necessary to make the accurate mathematics model of the control object, just need to summarize the operator’s experience and data to more perfect language control rules. So the system has a good robustness and is better used in non-liner control [5-7].

The paper adopts fuzzy control to compensate the unknown part system which just ensures $|f - f_0| < |f|$. The proposed controller is used to servo system’s position controller. The experiment results show that the fuzzy control compensator ensures the control quality and easy to realize.

2. An active disturbances rejection controller based on fuzzy compensator

The diagram of an active disturbances rejection controller based on fuzzy compensator is shown as follow. The block diagram is shown in figure 1.

Smoothed command signals and velocity feed forward signals are generated with TD adopted for smoothing of command signals, of which, the system’s input command signal $x(t)$ generates two output signals $x_1(t)$ and $x_2(t)$ when it is input into TD, and $x_1(t)$ tracks the input command signal $x(t)$ while $x_2(t)$ is $x_1(t)$’s differentiation, i.e., velocity feed forward signal.

It is presumed that the servo system is a second order system:

$$\ddot{y} = f(y, \dot{y}, t) + bv$$

(1)

Figure 1. Block Diagram of active disturbances rejection controller based on fuzzy compensator.

Then, the discrete second order TD is described with the following equations:

$$\begin{align*}
\{x_1(k+1) &= x_1(k) + h \cdot x_2(k) \\
\{x_2(k+1) &= x_2(k) + h \cdot f_0(x_1(k), x_2(k), x(k), r, h)
\end{align*}$$

(2)

In which $f_0(*)$ is provided by the following equations [2]:

$$\begin{align*}
f_0 = \begin{cases}
\delta = h\tau, \delta_1 = h\delta \\
e(k) = x_1(k) - x(k), e_1(k) = e(k) + h\dot{x}_2(k) \\
f_0(x_1(k), x_2(k), x(k), r, k) = \begin{cases}
-x \cdot \text{sign}(g(k)), |g(k)| \geq \delta \\
-rg(k) / \delta, |g(k)| < \delta
\end{cases} \\
g(k) = \begin{cases}
x_1(k) - \text{sign}(x_1(k))(\delta - \sqrt{\delta^2 + 8r} / 2), |x_1(k)| \geq \delta_1 \\
x_1(k) + \frac{\delta_1^2}{8r}, |x_1(k)| < \delta_1
\end{cases}
\end{cases}
\end{align*}$$

(3)
ESO is used for estimation of position feedback signal \( y \) so as to smooth and recover feedback position signal \( y_1(t) \) as far as possible, detect its approximate differential feedback velocity signal \( y_2(t) \) and estimate the sum \( y_3(t) \) of the systems disturbance.

Then, the discrete ESO [3] is:

\[
\begin{align*}
    y_1(k+1) & = y_2(k) - \beta_1 E_4(y_1(k) - y(k)) \\
    y_2(k+1) & = y_3(k) - \beta_2 E_4(y_1(k) - y(k)) + bx(k) \\
    y_3(k+1) & = -\beta_3 E_4(y_1(k) - y(k))
\end{align*}
\]  

In which

\[
E_4(y_1(k) - y(k)) = \text{fal}(y_1(k) - y(k), a_k, \xi)
\]

An active disturbances rejection controller based on fuzzy compensator adopts fuzzy control to compensate the unknown part system.

Then, the discrete ESO [3] is:

\[
\begin{align*}
    y_1(k+1) & = y_1(k) - \beta_1 E_4(y_1(k) - y(k)) \\
    y_2(k+1) & = y_2(k) - \beta_2 E_4(y_1(k) - y(k)) + f_0 + bx(k) \\
    y_3(k+1) & = -\beta_3 E_4(y_1(k) - y(k))
\end{align*}
\]  

Non-Linear PID Compound Control

Compare the smoothed command signal \( x_1(t) \) generated by TD with the position feedback signal \( y_1(t) \) measured by ESO to generate position error signal \( e_1(t) \), and compare command velocity signal \( x_2(t) \) generated by TD with velocity feedback signal \( y_2(t) \) measured by ESO to generate error variance signal \( e_2(t) \), and integrate position error signal \( e_1(t) \) to obtain input \( e_0(t) \) into non-linear PID control for signal non-linear combination, and simultaneously eliminate the measured disturbance \( y_3(t) \) and compensate the output control signal \( u_1(t) \) with the feed forward compensation signal.

Non-linear PID control is constructed with non-linear state error feedback control law:

\[
\begin{align*}
    e_1(k+1) & = x_1(k) - y_1(k) \\
    e_2(k+1) & = x_2(k) - y_2(k) \\
    e_0(k+1) & = \int_0^t e_1(k) \, dt
\end{align*}
\]

\[
u(k+1) = k_p \text{fal}(e_1(k+1), a_1, \xi_1) + k_i \text{fal}(e_0(k+1), a_0, \xi_0) + k_d \text{fal}(e_2(k+1), a_2, \xi_2)
\]

In which:

\[
\text{fal}(x(k), a, \xi) = \begin{cases} 
    |x(k)|^a \text{sign}(x(k)), & |x(k)| \geq \xi \\
    |x(k)|^a \xi^{1-a}, & |x(k)| \leq \xi 
\end{cases}
\]

\( y_1,y_2 \) is the input signals of fuzzy control , the estimated value \( y_1 \) is the output signal of fuzzy control, which is compensated the unknown part of controlled object model and reduce the heavy burdens of extended state observer. Then increase the estimate precision of extended state observer and improve control quality of active disturbances rejection controller.

Then, an active disturbances rejection controller based on fuzzy compensator are added finally:

\[
u_1(k+1) = u(k+1) - (y_3(k) + f_0)/b
\]

3. Experiment results

The proposed active disturbances rejection controller based on fuzzy compensator is applied in a servo system position controller.
Its parameters of TD are: $h=0.002\text{sec}$, $r=200000$, $\delta=1100$, and $\delta_1=230$, while the parameters of ESO are: $\beta_1=45$, $\beta_2=95$, $\beta_3=135$. Tektronix oscillograph TDS1012 is adopted in measurement. The experimental result is compared with ADRC.

It is shown in the figures that the performance of active disturbances rejection controller based on fuzzy compensator is improved under the system’s parameters is the same.

Figure 2 and figure 3 are the $65^\circ$/$s$ constant velocity error curve using ADRC an ADRC based on fuzzy compensator. It is shown in the figures that, compared to ADRC, the error in ADRC based on fuzzy compensator control distinctively become smaller, reduced from 0.8mrad in ADRC control mode to 0.2mrad.

Figure 4 and figure 5 are $120^\circ$ restting motion error curve of ADRC control and ADRC based on fuzzy compensator control. It is shown in the figures that, compared to ADRC control mode, ADRC based on fuzzy compensator control, its transfer response is quick and curve of braking is smooth.

What is shown in figure 6 and figure 7 are the error curve of sinusoidal motion in amplitude of 60° and period of 5.4 seconds using ADRC an ADRC based on fuzzy compensator. It is shown in the figures that, compared to ADRC, the error in ADRC based on fuzzy compensator control is distinctly small and is reduced from 0.9mrad in ADRC control mode to 0.6mrad, and its precision is promoted dramatically.
4. Conclusion
The paper adopts fuzzy control to compensate the unknown part system which just ensures $|\tilde{f}_e-f_0|<|f|$ less than $|f|$. Experiment results show that the proposed active disturbances rejection controller based on fuzzy control compensates the controlled object reduces the heavy burdens of extended state observer. Then it increases the estimate precision of extended state observer, and makes wider variations ranging of control parameters and easy to realize.

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