AN WINDUP COMPENSATOR FOR SYSTEMS WITH SATURATION ACTUATORS USING ADAPTIVE FUZZY LOGIC

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Abstract: In this paper, we test fuzzy logic-based compensation method for PID controller and conditioned Technique and compare their performance. As this compensation aims to diminish the effect of windup, it is referred to as anti-windup (AW). We consider two cases: set point tracking and disturbance rejection. For set point tracking and disturbance rejection, the fuzzy compensator shows better performance than the conditioning technique. The presented control scheme is composed of a fuzzy logic based compensator and a conventional PID controller. Copyright © 2002 IFAC

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1. INTRODUCTION

Industrial processes impose nonlinear limits on their process variables, while linear design techniques assume that there are no such limits. All physical systems need actuators for achieving control and these are subject to saturation.

The actuator not only deteriorates the performance of the control system, but can also lead to instability since the feedback loop is broken in such situations. When a linear controller shows integral action, the controller output can exceed the saturation level quickly. This can result in serious performance degradation such as large overshoots and large settling times.

One of the widely used Anti Windup schemes is to provide a local arrangement, using the difference between the controller output signal "u" and the saturated control "ur", around the controller. This compensation scheme is somewhate standard for saturation systems. Although, there are several known results for the conditioning technique, the high gain conventional scheme, and the equilibrium point matching method and so on...(D.Vrancic, et al., 1995; R.Hanus, et al., 1987).

Windup problems were originally encountered in PI/PID controllers. However, it was recognized later that the integrator windup is only a special case of a more general problem.

Substantial research has been done to incorporate modifications into controllers, which have been designed without accounting for constraints, such that the closed loop behavior is satisfactory even in the presence of constraints.

The modifications are usualy called anti windup schemes. Most of the existing anti windup schemes modify the control law only when the actuator is saturated. In this paper, a fuzzy logic AW compensator to control process is presented. The fuzzy control rules are built based on mathematical reasoning. A set of variable width membership functions is used to perform the fuzzification of the measurement instead of a set of uniform width membership functions. A weight parameter is introduced to build the control rules to improve the performance of the fuzzy logic AW compensator's.

The remainder of the paper is organized as follows. In section 2 and 3 ,we formulate respectively the conditioning technique and the fuzzy Logic AW compensator. In section 4, we will simulate the conditioned Technique and fuzzy compensator for the model and compare their performance for set point tracking and disturbance rejection. Finally, some concluding remarks will be drawn in section 5.

2. ANTI WINDUP COMPENSATION

The windup phenomenon usually results in high overshoots and longer settling times of the process variable.

The role of AW Compensation is to minimize the adverse of limitations on closed-loop performance.

The most common types of limitations are magnitude and rate limitations. Consider a closed-loop system containing PID controller and a magnitude limitation which can be described by the following equation :

$$ur(t)=\begin{cases} u_{max} & \text{si} \quad u(t)>u_{max} \\ u(t) & \text{si} \quad u_{min}\leq u(t)\leq u_{max} \\ u_{min} & \text{si} \quad u(t)<u_{min} \end{cases} \qquad (1)$$

Assume a large positive step change in w that causes a jump in u, so that the actuator saturates at high limit if K>0. Thus, "ur" becomes smaller than u, and y is slower than in the unlimited case. The integral term increases much more than one in the unlimited case, and it becomes large.

When y approaches w, "ur" still remains saturated or close to saturation due to the large integral term; u decreases after the error has been negative for a sufficiently long time. This leads to a large overshoot and a large settling time of the process output. Windup appears due to the fact integral term increases too greatly during saturation. Thus, during saturation the increase should be slowed down. This can be realised by an extra compensation that feeds back u-ur to the integral term through an anti-windup compensator with a transfer function F(s)=1/K (see figure 1) (Park and Choi 1994; Hanus and Bogaerts 2000). Where "u" and "ur" are also reffered to respectively as the controller output and the real process input y is the process output. w is the reference signal. e=w-y is the process tracking error. d is the disturbance. The controller parameters are the proportional gain K, the integral time constant Ti, and the time derivative constant Td. The high frequency gain N is usually set between 7 and 15.

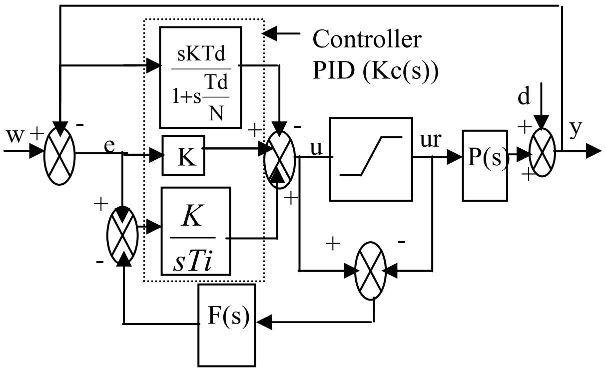


Fig.1 The observer type compensation

A PID controller (Kc(s)) can be described by the following equation:

$$U(s)=K\left[E(s)+\frac{1}{sTi}E(s)-\frac{sTd}{1+s\dfrac{Td}{N}}Y(s)\right] \qquad (2)$$

The capital letters U,E and Y denote the Laplace transforms of u,e and y respectively.

3.FUZZY LOGIC AW COMPENSATOR

In this section we describe the basic structure of the control scheme, and motivate the rationale for the fuzzy compensator. The structure of PID-Fuzzy compensator controller is shown in Figure 2. The scheme consists of a conventional PID control structure together with our proposed fuzzy compensator AW. The compensator has two inputs, "v" and "dv/dt" and one output "ua".

When the controller output can't exceed the saturation, the output from fuzzy compensator is zero. When a saturation is observed, fuzzy compensator generates an additional control signal "ua". The adjustment of the integral action of PID is necessary for the compensations of the overshoot amount and settling time of the process output.

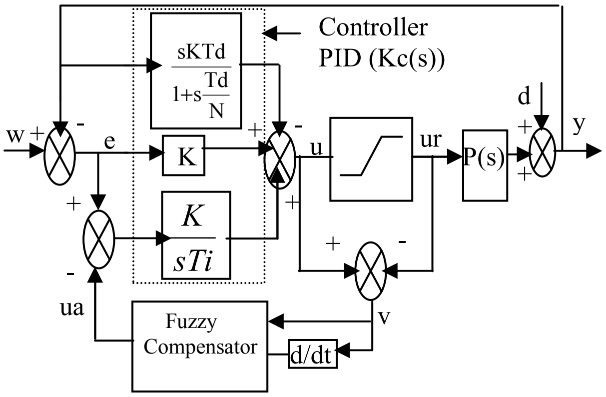


Fig.2 The structure of PID-Fuzzy compensator AW

A fuzzy logic compensator describes complex systems with linguistic descriptions. The information is described in terms of fuzzy sets. Unlike conventional controllers, three steps have to be performed by a fuzzy logic compensator before it may generate desired output. These three steps are (Ying, 2000; Driankov , et al., 1993) :

(1) fuzzification of the input
(2) fuzzy inference based on the knowledge base;
(3) defuzzification of the fuzzy control signal.

3.1 Fuzzification

The first step performed by a fuzzy compensator is to fuzzify each input. This can be done by associating each input with a set of fuzzy variables. In order to denote fuzzy variables in numerical sense, a membership function is assigned with each fuzzy variable. By doing so, we can denote the meaning of an input in terms of linguistics. The value of the membership function varies between zero and one. In order to improve the performance of the fuzzy logic controller, variable width membership functions are used as shown in Figure 3.

NE : Negative
NL : Negative Large
ME : Medium
PO : Positive
MI : Minimum
ZE : Zero
PL : Positive Large
MA : Maximum

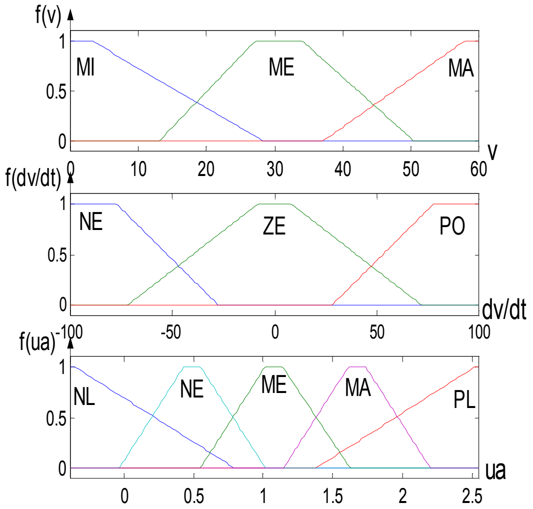


Fig.3 Variable width fuzzy membership functions

3.2 Fuzzy rule-base

Fuzzy control rules are the heart of a fuzzy logic compensator. Determining the suitable fuzzy control rules is the major part of a fuzzy compensator design. Each of these control rules has IF... THEN... statement. By matching the fuzzified inputs with each control rule will generate a set of control signals. In this research, two inputs are used for the fuzzy compensator. One is error v (v=u-ur). The other is velocity error dv/dt.

Table 1 lists a complete set of fuzzy control rules of the fuzzy logic controller. In order to improve the performance of the fuzzy logic compensator, a weight parameter is used to impose different weights on v and dv/dt to obtain the control signal:

$$z=-(\alpha . v+(1-\alpha). dv/dt\,) \qquad 0<\alpha<1 \qquad (3)$$

where α is the weight parameter, z is the fuzzy control signal. A better control performance could be obtained by adjusting the weight parameter α.

Table1. Fuzzy control rules

		v		
		MI	ME	MA
dv/dt	NE	NE	MA	MA
	ZE	NL	ME	MA
	PO	NE	MA	PL

3.3 Defuzzification

Since the above control signal is in fuzzy mode, defuzzification is required to transform fuzzy control signal into exact control output. The weighted centroid method is applied to defuzzify the fuzzy control signal. This method can be expressed as:

$$Z=\frac{\sum_{i=1}^{n}\beta_i z_i}{\sum_{i=1}^{n}\beta_i} \qquad (4)$$

where β_i is the weighting parameter, and z_i is the fuzzy control signal, n represents the number of elements of the membership function, Z is the defuzzified control output. This method can produce a smooth control output because it considers the contribution of all fuzzy inputs instead of only one of them.

4. ILLUSTRATIVE EXAMPLE

Set point tracking and disturbance rejection are two of the main purposes of using control systems. Set point tracking means that when the desired value of a controlled variable changes from one set point to the other, the control system should make the controlled variable converge to its new desired value. A good controller should make the convergence quickly with small or no overshoot and oscillation. Disturbance rejection means that when there is an external disturbance to the system that makes the controlled variables away from their set points, the control system should make the controlled variables back to their set points. Similar to set point tracking, a good controller should make the backing to the set points quickly with small oscillation. In this section, we apply the Conditioned Technique and fuzzy compensator designed in the last section to the model. We will compare their performance against set point tracking and disturbance rejection.

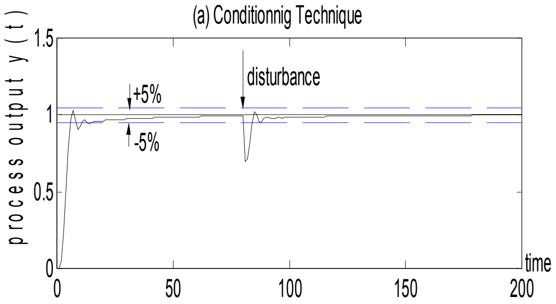
In order to illustrate the above phenomenon, we have made a simulation with process:

$$P(s)=1/(1+4s)(1+s)^2 \qquad (5)$$

Using a pole-placement method, the following PID controller for the process was derived :

K = 10, Ti=30s , Td=0.5s, N=10
The input limitation are Umax=2 , Umin=0

The results obtained by simulation using the MATLAB-SIMULINK program package are shown in figure 4a and figure 4b. Figure 4 show the process outputs obtained when using The conditioning Technique and Fuzzy Compensator method. The reference w changes from 0 to 1 at time t=0. We see that the fuzzy compensator gave quicker convergence than the Conditioned Technique. When a 30% disturbance (d) to the output was added , we see that the fuzzy compensator give a good performance than the Conditioning Technique.


(a) Conditionnig Technique

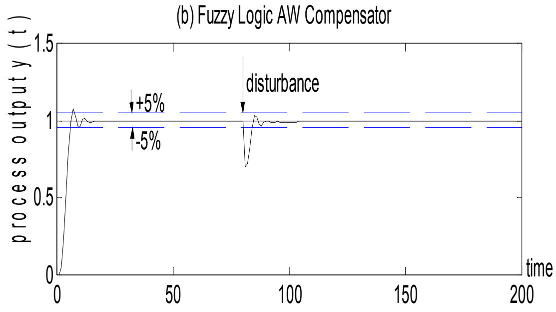

(b) Fuzzy Logic AW Compensator

Fig.4 Step responses

5.CONCLUSION

In this paper, we designed a fuzzy logic AW compensator scheme. The fuzzy compensator scheme showed better performance than the conditioning technique scheme for set point tracking and disturbance rejection. The fuzzy compensator are each constructed from the 9 rules.

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