AN IMPLEMENTATION OF PEAK OBSERVER BASED SELF-TUNING FUZZY PID-TYPE CONTROLLER ON PLC

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ABSTRACT

In this study, peak observer based tuning method that adjusts the input scaling factor corresponding to the derivative coefficient and the output scaling factor corresponding to the integral coefficient of the PID type fuzzy logic controller is implemented on PLC. The results of the peak observer based self-tuning fuzzy PID-type controller is compared with the fuzzy PID-type controller without a tuning mechanism. It has been observed that the tuning mechanism implemented via PLC decreases the oscillations and the settling time while providing a smoother system response.

I. INTRODUCTION

Fuzzy logic is extensively used in processes where system dynamics are either very complex or exhibit a nonlinear character. The first fuzzy logic control algorithm implemented by Mamdani [1] was constructed to synthesize the linguistic control protocol of a skilled human operator. Although, this type of fuzzy logic controller (FLC) application was successful compared to classical controllers, the design procedure is dependent on the experience and knowledge of the operator and it is limited by the elucidation of the heuristic rules of control. In order to avoid this major difficulty or drawback of depending on the control experience of the operator, Mac Vicar-Whelan [2] firstly proposed some general rules for the structure of fuzzy controllers. These fuzzy rules devised by Mac Vicar-Whelan approach to a deterministic (PI) or (PD) controller in the limit as quantization levels of control and measurement variables become infinitely fine [3].

In literature, various types of fuzzy PID (including PI and PD) controllers have been proposed. In general, the application of fuzzy logic to PID controller design can be classified into two major categories according to the way of their construction [4]:

i. The gains of the conventional PID controller are tuned on-line in terms of the knowledge base and fuzzy inference, and then the conventional PID controller generates the control signal [5, 6].

ii. A typical FLC is constructed as a set of heuristic control rules, and the control signal is directly deduced from the knowledge base and the fuzzy inference as it is done in Mc Vicar-Whelan or diagonal rule-base generation approaches [7-9].

The controllers in the second category are referred to as PID type FLCs because, from the input-output relationship point of view, their structures are analogous to that of the conventional PID controller. The equivalence of PD type FLC's and conventional PD controllers has been established under special conditions [10, 11].

Fuzzy PI-type control is known to be more practical than fuzzy PD-type because it is difficult for the fuzzy PD to remove steady state error. The fuzzy PI-type control is, known to give poor performance in transient response for higher order processes due to the internal integration operation. Theoretically, fuzzy PID type control should enhance the performance a lot. It should be pointed out that, for fuzzy PID controllers, normally a 3-D rule base is required. This is difficult to obtain since 3-D information is usually beyond the sensing capability of a human expert. To obtain proportional, integral and derivative control action all together, it is intuitive and convenient to combine PI and PD actions together to form a fuzzy PID controller [11-14]. The formulation of PID-type FLC can be achieved either by combining PI and PD type FLCs with two distinct rule-bases or one PD type FLC with an integrator and a summation unit at the output.

We can summarize the design parameters within two groups [15]:

a) structural parameters

b) tuning parameters.

Structural parameters include input/output (I/O) variables to fuzzy inference, fuzzy linguistic sets, membership functions, fuzzy rules, inference mechanism and defuzzification mechanism. Tuning parameters include

I/O scaling factors (SF) and parameters of membership functions (MF). Usually the structural parameters are determined during off-line design while the tuning parameters can be calculated during on-line adjustments of the controller to enhance the process performance, as well as to accommodate the adaptive capability to system uncertainty and process disturbance.

There exist various heuristic and non-heuristic tuning strategies for the adaptation of scaling factors of fuzzy controllers [16-18]. The peak observer idea given in [11] proposes a simple tuning structure that needs no additional designer parameter. It basically keeps watching on the system's output and transmits a signal at each peak time to adjust the input scaling factor corresponding to the derivative coefficient and the output scaling factor corresponding to the integral coefficient of the PID type fuzzy logic controller.

In this study, we will deal with fuzzy PID type controllers formed using one PD type FLC with an integrator at the output. In this kind of PID type FLC, the number of scaling factors is decreased compared to the PID type FLC formed by combining PI and PD type FLCs with two distinct rule-bases. However, the adjustment of the scaling factors becomes more crucial as compared to the former case mentioned above. Therefore, peak observer based self-tuning mechanism is used for the adaptation of the scaling factors of the PID type FLC. The peak observer based self-tuning fuzzy PID-type controller is implemented on Simatic S7-200 PLC to control various plants formed on FEEDBACK PCS 327 Process Control Simulator. The results are compared with the fuzzy PID-type controller without a tuning mechanism.

The outline of the paper can be summarized as follows: Section 2 discusses the fuzzy PID type controller structures with and without tuning mechanisms, section 3 presents the peak observer based self-tuning method, whereas, sections 4 and 5 provide the implementation results and the discussions and also the conclusions, respectively.

II. FUZZY PID-TYPE CONTROLLER WITHOUT A TUNING MECHANISM

In this study, we will consider a controller structure as it is shown in Figure 1.The output of the fuzzy PID type FLC is given by

$$u = \alpha U + \beta \int U dt \qquad (1)$$

where U is the output of the FLC.

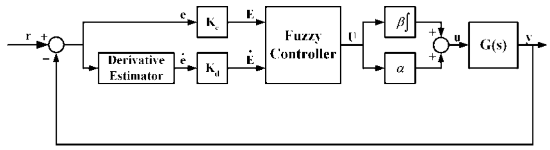

Figure 1. The closed-loop control structure for PID type FLC

It has been shown in [10, 11] that the fuzzy controllers with product–sum inference method, center of gravity defuzzification method and triangular uniformly distributed membership functions for the inputs and a crisp output, the relation between the input and the output variables of the FLC is given by

$$U = A + PE + D\dot{E} \qquad (2)$$

where $E = K_e.e$ and $\dot{E} = K_d.\dot{e}$. The same result is shown to be valid for the minimum inference engine in [19]. Therefore, from (1) and (2) the controller output is obtained as

$$\begin{aligned} u = \alpha A + \beta At + \alpha K_e Pe + \beta K_d De \\ + \beta K_e P \int edt + \alpha K_d D\dot{e} \end{aligned} \qquad (3)$$

Thus, the equivalent control components of the PID type FLC are obtained as follows:

$$\begin{aligned} &\textbf{P}\text{roportional gain}: \alpha K_e P + \beta K_d D \\ &\textbf{I}\text{ntegral gain} \quad : \beta K_e P \\ &\textbf{D}\text{erivative gain} \quad : \alpha K_d D \end{aligned} \qquad (4)$$

III. PEAK OBSERVER BASED SELF-TUNING FUZZY CONTROLLER

Parameter adaptive PID type FLC using a peak observer has been proposed in [11]. The block diagram of the proposed method is shown in Figure 2. The peak observer keeps watching on the system's output, transmits a signal at each peak time, and measures the absolute peak value. The parameter regulator tunes the controller parameters K_d and β simultaneously at each peak time according to the peak value.

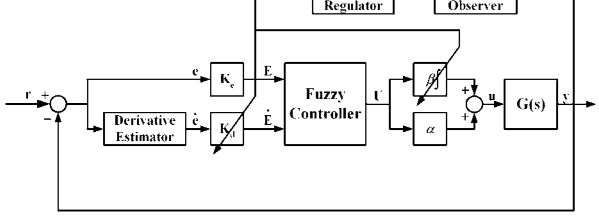

Figure 2. The closed-loop control structure for parameter adaptive PID type fuzzy logic controller via peak observer

The algorithm for tuning these parameters is as follows:

$$K_d = \frac{K_{ds}}{\delta_k}, \qquad \beta = \delta_k \beta_s \tag{5}$$

where K_{ds} and β_s are the initial values of K_d and β. δ_k values are the peak values as it is shown from the typical step response of a second order system in Figure 3. It can easily be deduced from the relation given in (4) that if in the meanwhile of decreasing β, K_d is increased in the same rate as β is decreased, the equivalent proportional control strength will remain unchanged. Then, the system can always keep quick reaction against the error under this condition. This is achieved by updating the integral coefficient as the reciprocal of the derivative coefficient.

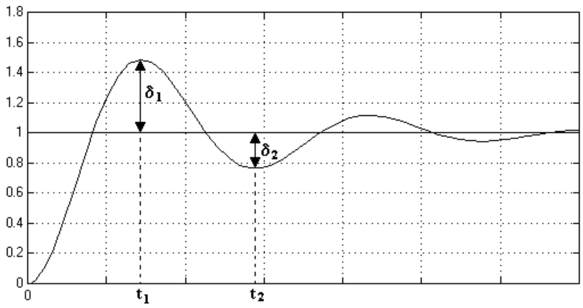

Figure 3. Different phases of the step response of a control system.

IV. IMPLEMENTATION

A PLC can be defined as a microprocessor-based control device, with the original purpose of supplementing relay logic. Early PLCs were able to perform only logical operations. PLCs can now perform more complex sequential control algorithms with the increase in microprocessor performance. On the other hand, they can use analog inputs and outputs. Therefore, today the majority of specialists agree that the real future of PLCs lies not only in traditional discrete process control, but also in the area of demanding continuous and, particularly, batch processes, which are a combination of continuous and discrete processes – a sequence of continuous activities, performed in a logical order. Thus, today a typical PLC-based application deals with several hundreds of analogue and digital inputs and outputs, while performing quite complex control procedures [20]. Therefore, the peak observer based self-tuning fuzzy PID type controller is implemented using Simatic S7-200 CPU 214 processor and EM 235 analog I/O unit on FEEDBACK PCS 327 Process Control Simulator.

The following two different systems are formed on the process simulator.

$$\text{System I: } G_1(s) = \frac{1}{(s+1)^2}$$

$$\text{System II: } G_2(s) = \frac{1}{s+1} e^{-s}$$

In order to choose the initial scaling factors of the FLC, all the simulations are carried out on a MATLAB®/ SIMULINK™ platform. Then, fuzzy PID-type controller with the peak observer based FLC tuner is implemented on Simatic S7-200. The reference value is chosen as 5 V and the total duration of implementation time is taken as 20 s in the real run of the experiments.

SYSTEM I: SECOND ORDER LINEAR SYSTEM

The scaling factors of the PID-type FLC are chosen as follows:

$$K_e=0.9 \quad K_{de}=0.6 \quad K_i=0.6 \quad K_d=1$$

The system output of the Process Simulator is oscillatory when a Fuzzy PID-type PID controller without a self-tuning mechanism is used. Then, Peak Observer based tuning mechanism is applied the response becomes smoother and less oscillatory as given in Figure 4. During the implementation stage, it is noticed that small disturbances give unnecessary peak values, so a threshold with 0.25 V is used in real-time implementation. The related control signal is shown in Figure 5.

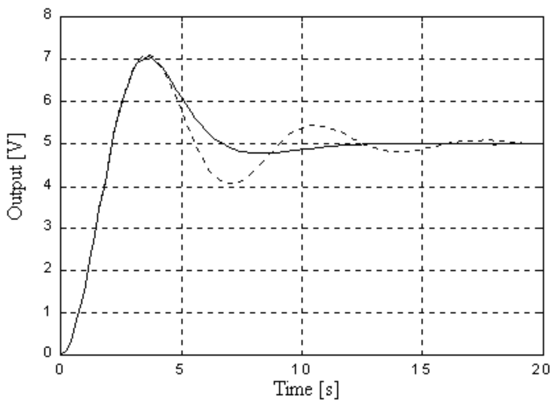

Figure 4. Step response of System I. (Dashed-line: PID-type FLC without a tuner; Solid-line: Peak observer based self- tuning Fuzzy PID-type controller)

Figure 8. Experimental setup used in the study.

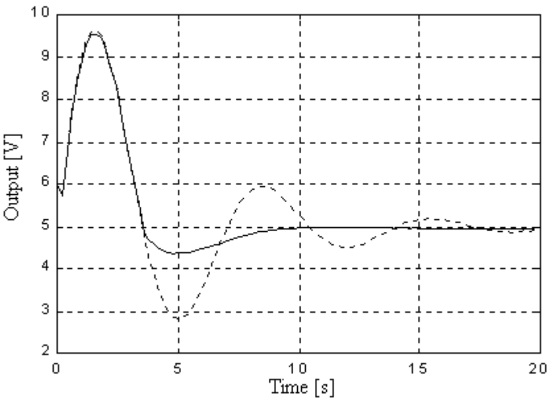

Figure 5. Control signal for System I. (Dashed-line: PID-type FLC without a tuner; Solid-line: Peak observer based self- tuning Fuzzy PID-type controller)

SYSTEM II: FIRST-ORDER LAG WITH DEAD TIME

The scaling factors of the PID-type FLC for this case are chosen as follows:

$$K_e=0.9 \quad K_{de}=0.7 \quad K_i=0.4 \quad K_d=1$$

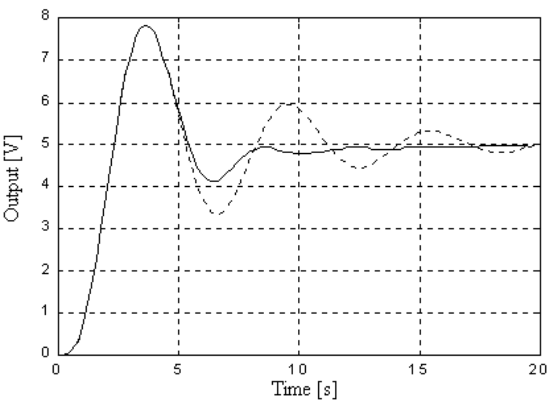

Figure 6. Step response of System II. (Dashed-line: PID-type FLC without a tuner; Solid-line: Peak observer based self- tuning Fuzzy PID-type controller)

The same experiment has been applied to the second system, which has a first-order lag with time delay. The step responses and the related control signals are given in Figure 6, and in Figure 7, respectively.

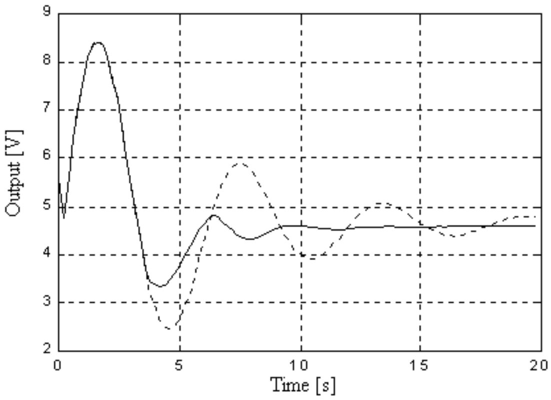

Figure 7. Control signal for System II. (Dashed-line: PID-type FLC without a tuner; Solid-line: Peak observer based self- tuning Fuzzy PID-type controller)

The settling time for this study is chosen as 5 percent of its final value, and all the settling time values of each system are given Table 1. The picture of the experimental setup built the laboratory is shown in Figure 8.

Table 1. Settling time values of each system

	SETTLING TIME (T_s)	
	PID-type FLC without a tuning mechanism	PID-type FLC with a peak observer based tuning mechanism
SYSTEM I	12	6.4
SYSTEM II	16.4	8

It can be seen from the implementation results given in Figure 4, Figure 6 and from the Table 1, the peak observer based self–tuning fuzzy PID-type controller produces a decrease in the settling time. On the other hand, because of its nature, it cannot remove the first peak. Therefore, this tuning mechanism is useful for the PID-type FLC in the case that the scaling factors are not tuned properly.

V. CONCLUSION

The PID type fuzzy logic controller that has been implemented on a PLC has been used in controlling various plants formed on a process simulator. The input scaling factor corresponding to the derivative coefficient and the output scaling factor corresponding to the integral coefficient of the PID type fuzzy logic controller has been adjusted using a peak observer based tuning method. Because of the nature of the peak observer, the first peak cannot be decreased or removed by the tuning algorithm.

It can only ameliorate the response after the occurrence of the first peak value. However, when either a parameter variation occurs in system parameters or the controller parameters are not set appropriately, the method proposed here will provide an enhancement in the system performance.

Moreover, conventional PID controllers are used almost in 90 percent of the industrial control systems, and wide range of them are implemented via PLCs, and a fuzzy PID-type controller with a self-tuning mechanism proposed in the paper can therefore be easily replaced by the existing conventional PID controllers.

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