Fuzzy Control Compared with Digital PID Control

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Abstract
This paper presents a comparative study of the fuzzy control algorithms with the most popular conventional control approach PID control (proportional integral derivative) in the case of a non-linear static process control.

Digital PID controller based on a MC68HC812A4 microcontroller evaluation board is developed. Same controller inputs - error and the change of error are used in coding the fuzzy control algorithm too. Therefore proper comparative analysis can be done. Both control algorithms were tested in a lead-acid battery charger.

Experimental results, advantages and disadvantages of both control systems are discussed in detail.

1. Introduction

The automatic control of industrial processes requires a greater accuracy, faster response times as well as design delays as short as possible.

Moreover, the environmental conditions of the processes create important constraints such as external disturbances (for example, on process control or on the measured output) or modifications of the system parameters (such as the ones due to aging). Besides, it is often difficult or even impossible to obtain a simple mathematical process modeling.

These various constraints can lead to the failure of conventional control approaches. Therefore, the use of fuzzy logic control, based on the expertise of the human operator, seems to be an interesting alternative.

Most controllers use the error, change of error as their input variables. The output action is determined by the difference between the set point and the error or change of error inputs. Classical PID controllers also use a similar method to determine the next output of the system. PID controllers have some difficulties in tuning for the whole range of working points. Mostly tuning procedure is done for a specific working point. When the working point changes their performance deteriorate and the errors at the output signal or the controlled variable tend to increase. Problems with tuning the PID controllers increase, when the system to be controlled has non-linear dynamics. Fuzzy control seems to be an interesting alternative, specially in the systems, which have non-linear characteristics. This paper analyses and compares the performance of a digital PID controller and a classical fuzzy controller both implemented with the microcontroller MC68HC812A4. Both controllers are used to control a charging of a Lead-Acid battery.

2. Implementation of a digital PID controller

2.1. Analogue PID algorithm

Analogue PID control algorithm is given as:

$$v_{out} = K_p e + K_i \int e dt + K_d \frac{de}{dt} \quad (1)$$

In analogue world, this algorithm is implemented (or solved) by the use of analogue computation blocks, such as multipliers, dividers, integrators, and differentiators. These analogue blocks are easily constructed using operational amplifiers. Proportional coefficient K_p, integral coefficient K_i, and derivative coefficient K_d, are set with the help of variable resistors in op-amp circuits. As a matter of fact, the gain adjustments (tuning) in analogue controllers are best carried out in field with process on line.

2.2. Digital PID algorithm

A digital control system is not a continuous but a discrete (sampled data) control system. In this system, error data is available only at regular sampling intervals, when samples are taken. Once a new set of data on error is available, a new controller output can be calculated. Thus, error input to a digital controller is a pulse train and the output is also a pulse train.

The idea behind a sampled data system is shown in figure 1:

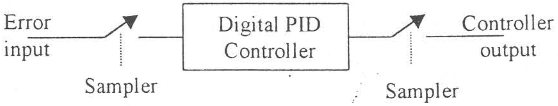

Figure 1: *Description of a sampling data system*

2.2.1. Proportional mode

Proportional output is simply the product of current error and proportional coefficient.

Current controller output = Current error x Proportional coefficient

In a digital PID controller this can be expressed as follows:

$$V(n) = K_p E(n)$$

where, $E(n)$ is the nth sample of the error input.

2.2.2. Integral mode

In integral mode, controller output is based upon the integral coefficient (time) and the past error history.

In an analogue controller this is expressed as:

$$v_0 = K_i \int e dt \quad (2)$$

The term $\int e dt$ is nothing but the area under the error-time curve as shown in figure 2.

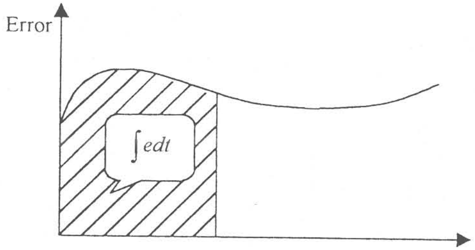

Figure 2: *Graphical representation of* $\int edt$

This can be expressed mathematically by:

$$\int edt = T\left[\frac{E(0)}{2} + 2E(1) + 2E(2) + \ldots + 2E(n-1) + \frac{E(n)}{2}\right] \quad (3)$$

where $E(i)$, i=1..n, are samples of the error variable.

An interesting observation can be made here. In the above expression for the area under the error curve, every single error term appears as a whole, except the very first and the last terms. This stems from the fact that over a large period of time, the trapezoidal rule essentially approaches the rectangular rule for calculation of area.

In a rectangular integration rule, error is assumed to have remained constant at the previous value and only changes at the sampling interval. Difference between trapezoidal calculation and rectangular calculation diminishes as the number of samples increases. This is a fairly valid assumption in real life; where a controller once put its service, will continue to operate. So simplifying the expression for area under the error curve, the integral at time t = nT $\int_{t=0}^{t=nT} edt$ is given as:

$$\int edt = T[E(0) + E(1) + E(2) + \ldots + E(n-2) + E(n-1) + E(n)] \quad (4)$$

$$\int edt = T\sum_{i=0}^{i=nT} E(i) \quad (5)$$

Correspondingly, controller output is :

$$V(n) = K_I T\sum_{i=0}^{i=nT} E(i) \quad (6)$$

2.2.3. Derivative control mode

In this operating mode, controller output is based upon the slope of the error (figure 3) curve at that time. In analogue PID controller we have:

$$v_0 = K_D \frac{de}{dt} \quad (7)$$

Instantaneous slope of the error curve provides information on the tendency of error. Thus a corrective action can be taken even before error has reached that level. This seems to provide a sort of intelligence to the controller and the name "anticipatory control".

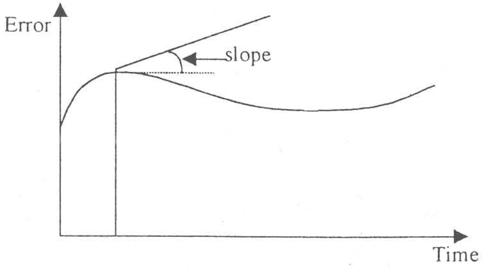

Figure 3: *Representation of the derivative part of the error variable*

In a sampled data system, since error infromation is only available at discrete interval, the slope can be estimated to be:

$$\frac{de}{dt} = \frac{E(n+1) - E(n)}{T} \qquad (8)$$

Unfortunately, $E(n+1)$ data is a future value and is not available at this instant ($t = nT$). So the next best estimate of slope is made using the present error $E(n)$, and the previous error $E(n-1)$. Controller output $V(n)$ can thus be calculated:

$$V(n) = K_D\left[\frac{E(n) - E(n-1)}{T}\right] \qquad (9)$$

2.2.4. Ideal digital PID algorithm

Combining all three modes of control, the controller output is:

$$V(n) = K_p E(n) + K_I T \sum_{i=0}^{i=nT} E(i) + \frac{K_D}{T}\left[E(n) - E(n-1)\right] \qquad (10)$$

This algorithm is also known as the position algorithm. It is considered to be safe algorithm where a temporary loss of control; e.g., controller malfunction or loss of communication can be tolerated. In such a case, after the restoration of fault, the control system will act to recover and eventually reach the desired state.

3. Fuzzy control algorithm

Fuzzy control algorithm is explained in details in [2], [3] and [4]. Figure 4 shows the fuzzy algorithm implemented in the microcontroller.

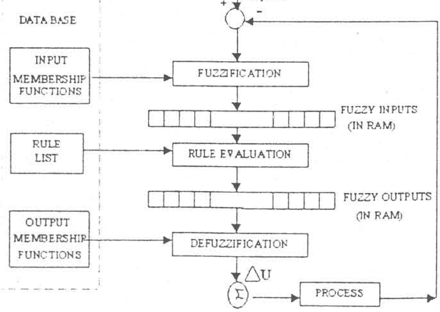

Figure 4: *Fuzzy algorithm of the controller*

It contains of three main steps: Fuzzification, rule evaluation and defuzzification. These are described in [2]. Figure 5 shows the rule base used in the fuzzy algorithm:

De \ e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NM	NS	Z	PS	PM
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PM	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Figure 5: *Rule base for the fuzzy algorithm*

3. Experimental setup and experimental results

The experimental setup is shown in figure 6. A Lead-Acid battery with 55Ah capacity was used in the experiment.

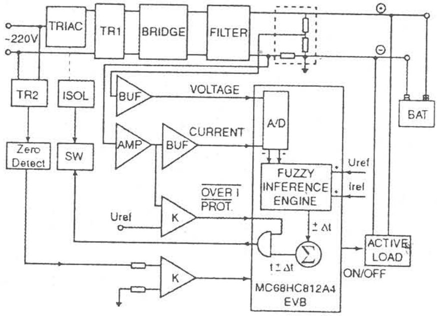

Figure 6: *Experimental setup*

Figure 7 shows the current-time curve for the PID regulator, and figure 8 shows the current-time curve for the fuzzy controller.

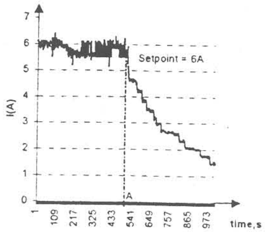

Figure 7: *Current-time curve for the Digital PID controller*

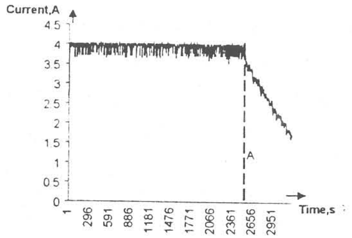

Figure 8: *Current-time curve for the Fuzzy controller*

4. Conclusion

Performance of a Digital PID controller and a fuzzy controller for a Lead-Acid battery charge has been compared. Both were designed and implemented with MC68HC812A4 evaluation board [1]. Digital PID controller shows some overshoots and undershoots during the charging. It is not stable during the changing of the charging stages. In contrast the fuzzy controller shows superior performance over the digital PID controller. It is smooth during the whole charging process and is stable during the changing of the charging stages.
Therefore fuzzy controllers can be recommended to control non-linear processes.

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