FUZZY SYSTEMS WITH PULSE WIDTH MODULATED CONTROL

NITU COSTICĂ

Politehnica University of Bucharest

Abstract: Digital controllers with PWM control signals represent a competitive method that offers the performance and economy of a hardware-based solution. These systems with the flexibility of a processor-based solution are used in control systems for fast and slow processes. In the paper a fuzzy control system with PWM control signals is presented and the hardware and simulation results are given to verify its feasibility. It promises enhanced system performance, added flexibility, reduced size and ultimately lower cost.

Keywords: Process Control, Digital controllers with PWM

1. INTRODUCTION

Pulse width modulation (PWM) is a technique for controlling analog circuits and actuators with a processor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion. An analog signal for actuator control has a continuously varying value, with infinite resolution in both time and magnitude. As intuitive and simple as analog control may seem, it is not always economically attractive or otherwise practical. For one thing, analog circuits tend to drift over time and can, therefore, be very difficult to tune. By controlling analog actuators digitally, system costs and power consumption can be drastically reduced. Now many microcontrollers and DSPs already include on-chip PWM controllers, making implementation easy. The PWM signal is still digital because, at any given instant of time, the full DC supply is either fully on or fully off. The voltage source is supplied by actuators to the analog load by means of a repeating series of on and off pulses. In the ON/OFF mode the *on-time* is the time during which the DC supply is applied to the load, and the *off-time* is the period during which that supply is switched off. For many control systems given a sufficient bandwidth, any analog control value can be encoded with PWM.

2. ACTUATORS WITH WIDTH MODULATED CONTROL SIGNAL

Actuator electromagnets are typically controlled in ON/OFF mode with a simple electronic controller. A digital controller increases actuator system flexibility by executing complex algorithms from both the output controlled position and dynamic points of view. Plus, the fast response of electromagnetic systems drives the need for actuator systems to use a highperformance controller in conjunction with dedicated peripherals for human operators. Systems based on digital controllers require fewer components, which decreases the mean time before failure (MTBF) of the system. The added capability of monitoring protection and prevention also increases the system reliability. For instance, an engineer can choose to monitor the system temperature to decrease the current limit level.
Over the years, new technologies has continued to push digital integration, which in turn increasingly adds to the complexity of the power delivery system. There doesn't appear to be an end to the gate integration curve and therefore requires continued innovation in power delivery systems. Digital controllers are the building blocks of future innovation in power regulation. Digital controllers offer system flexibility and optimization through a

communication bus that just isn't achievable with today's analog controllers. Additionally, digital controllers offer improved time-to-market with ease of design and increased system reliability. An example is to use low frequency pulse width modulation (PWM) for fan speed control. However, PWM fan speed control can sometimes introduce unwanted acoustic noise at a frequency equal to that of the PWM itself. This is especially noticeable when PWM control is used with higher operating current (>300 mA) fans and at low operating speeds. Another example is found in multiphase supplies, where a digital pulse width modulator (DPWM) can provide very accurate matching among duty cycles for different phases.
Currently, digital solutions range from standard digital signal processors (DSPs) to the latest dedicated microcontrollers. These software-driven digital controllers have many advantages over their analog counterparts such as ease of design, flexibility, optimization, and improved system reliability. In addition, digital technique offers an overall more elegant solution to many of today's demanding power requirements. Fundamentally, digital architectures differ from analog in the fact that digital controllers use A/D converters to digitize current and voltage information where compensation and regulation is done using digital techniques (programmable filters etc.) Additionally, digital architectures utilize some form of program memory, which not only allows for more sophisticated monitoring and control schemes but also adds a software graphical user interface as a design tool. These interfaces are used in the design phase to configure the digital controller for specific design parameters. Finally, digital processes tend to exist in smaller geometries, offering lower-cost solutions where there is a high degree of circuit function integration.

3. PWM IN COMMUNICATION AND CONTROL

Digital control promises significant system performance gains resulting from complex control algorithms that are difficult to implement in analog controller. Digital control has reduced susceptibility to component tolerances. Other advantages include programmability, reduced development time, decreased component count, lower susceptibility to component aging and environmental conditions, improved manufacturing logistics and, ultimately, lower cost. While various implementations have been reported, the most common digital controller implementations can be grouped into three major types: programmable signal processor (typically a digital signal processor (DSP)), custom hardware, or some combination of both. The DSP executes discrete time calculations of control variable values in real time. The dedicated hardware-based approach uses fixed architecture state machines to execute the control algorithm. Hardware can be optimized for cost and performance making this a potentially lower-cost and more efficient approach than the DSP. However, this approach lacks flexibility because the control hardware cannot be significantly changed once fabricated. Therefore, the hardware must be designed for a specific end application, which adversely impacts non-recurring engineering cost and time-to-market and increases design risk.

4. FUZZY CONTROLLER FOR SLOW PROCESSES

The approach presented in this paper combines processor and fixed hardware architectures, extracting maximum benefit from each. The described architecture uses dedicated programmable signal processors to perform high-speed control calculations. Many microcontrollers include on-chip PWM units. Some microchip's include two, each of which has a selectable on-time and period. The duty cycle is the ratio of the on-time to the period; the modulating frequency is the inverse of the period. The software to start PWM operation includes:

- Set the period in the on-chip timer/counter that provides the modulating square wave
- Set the on-time in the PWM control register
- Set the direction of the PWM output, which is one of the general-purpose I/O pins
- Start the timer
- Enable the PWM controller

A very important problem in control systems with PWM control pulses for motor actuators is the suppressing electromagnetic and acoustic noise. For example in the fan control systems the most dominant source of acoustic fan noise is turbulent airflow, which is caused by fan operation at full speed. Employing fan speed control (where the fan is operated primarily at lower than full speed) minimizes this noise. PWM acoustic noise is caused by the impulse torque generated by the fan motor during each active PWM cycle. Reducing this acoustic noise involves slowing the slew rate of the PWM switching, thereby "smoothing" the PWM impulse torque profile. PWM noise, as well as inductive kick, can be reduced or eliminated by slowing the slew rate of the PWM drive signal to the fan. Even a small reduction in slew rate results in a significant reduction of the PWM noise. The noise-suppression circuit implementation is simple, requiring only the addition of a small capacitor to the base of the PWM power switching transistor. For very large fans (more than 500 mA operating current), DC speed control may be required.

5. FUZZY CONTROL WITH PULSE WIDTH MODULATED

A control system with a pulse width modulated control signal is simulated. The process being controlled is given by a transfer function model representing two time constants in series with a time delay. The principle of PWM is to keep the element in the *on* state (and in *off* state) so that the resulting *average* control signal is as specified. For a given process to command the given process actuator PWM elements operates with a fixed process command period, T_p . The part of the period where the PWM element is in on-state is denoted the duty cycle, which is measured in percent.

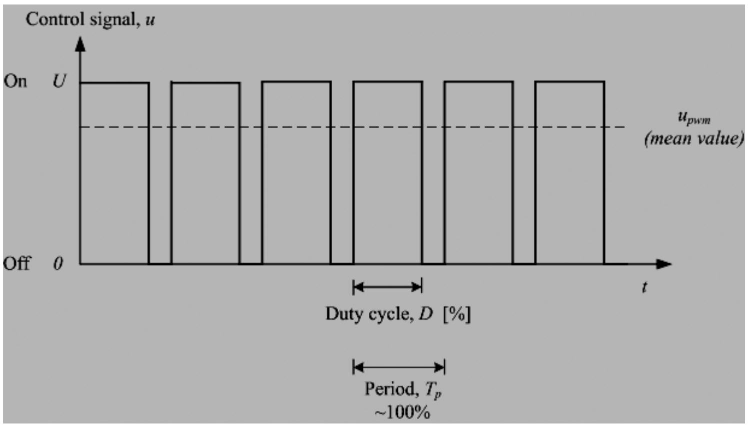

Fig. 1

In general, the less PWM period T_p, the smoother control signal for a given process. PWM is not proper for mechanical actuators as valves because of excessive wear. The aims of this simulator is to give an understanding of how pulse width modulation works, and to show how the control action works in a control system where the control signal is pulse width modulated. PWM is an important control technique. It is frequently used for controlling transistor based switches, as SSR elements (solid state relays) for controlling motors or valves. For the described fuzzy control system the following operations were adopted:

1. Set the controller in manual mode. The PWM period may be set to 1 sec. Control the process with a control signal (u_0) equal to 75%. Observe the PWM signal. Is the generated PWM signal 75% in average, as it should be?

2. Set the controller in automatic mode. Set y_{SP} to 75%. The fuzzy controller has the tuning parameters presented below. Is the control system behaving satisfactory regarding stability and average control error?

3. For comparison can be used a PID controller with settings K_{ip}, T_i, T_d and (according the Ziegler-Nichols' closed loop method). What is the average control error? How is the behavior of the PWM control signal?

In the design of the fuzzy controller the justification of the controller input and output variables consists in the choose of the membership function's shape and parameters by using their graphs. By using this method of design the parameters of the membership function are derived in accordance with the chosen graphs, and the equations are defined for the designed fuzzy controller. The control system structure with the fuzzy controller RLF is presented in fig. 2, where the plant is a oven, electric actuator is a controlled rectifier DCG or a transistor power swith, connected to the heating resistance R and the transducer is a thermocouple.

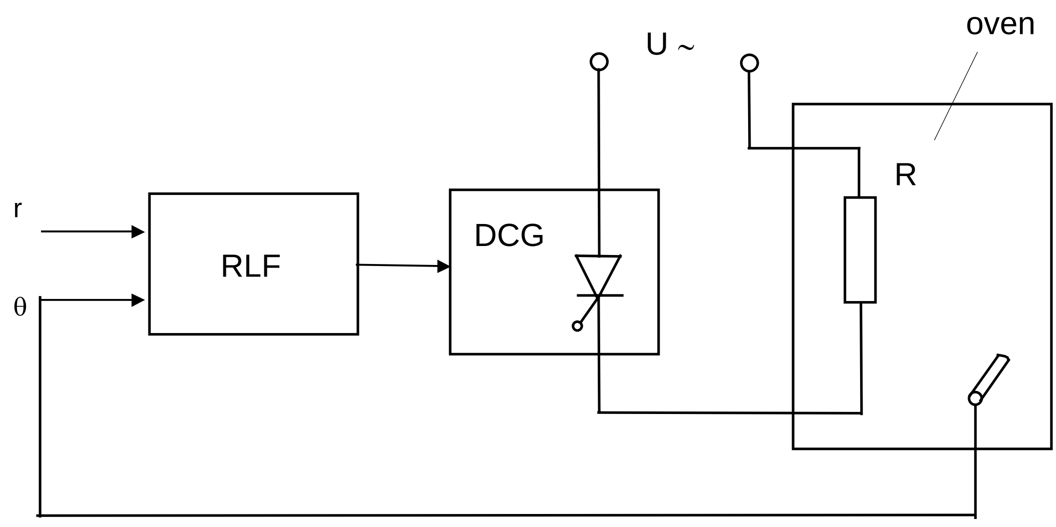

Fig. 2

The first block inside the controller is FUZZIFICATION, which converts each piece of input data to degrees of membership by a lookup in one or several membership functions. The fuzzification block thus matches the input data with the conditions of the rules to determine how well the condition of each rule matches that particular input instance. The choose membership functions for control deviation are presented in figure 3.

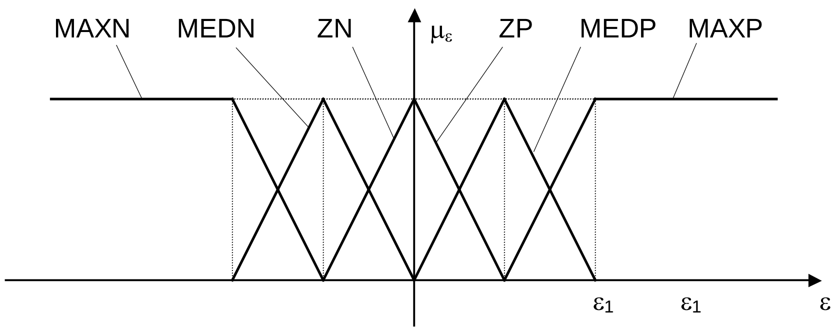

Fig. 3

The choose membership functions for control value are presented in figure 4. The maximum power of the electrical actuator is PMAX. and PMIN, PMIC, PMED are intermediary values, where some of these can be zero.

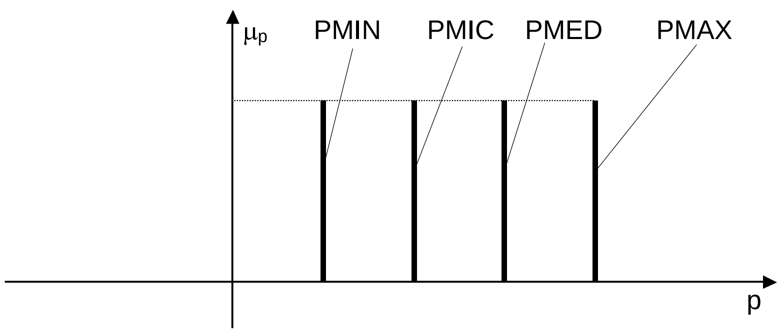

Fig. 4

The rules may use several variables both in input condition and conclusion of the rules. The controller can therefore be applied to both multi-input-multi-output (MIMO) problems and single input-single output problems (SISO), as for the case study the rules are presented in the table 1:

Table 1.

Deviation	MAXN	MEDN	ZN	ZP	MEDP	MAXP
P	PMIN	PMIN	PMIN	PMIC	PMED	PMAX

For defuzzification the Center of Area method C_0A is used and the relations for power calculation value P_c are obtained. The output value of the fuzzy controller is a power P_c which at the beginning of the each controller time period T_c is converted by the digital controller to a time interval t_C . Depending of the process time constants and delay of the process the PWM period T_p can differ of the controller period T_c because in many cases a multichannel controller is used. In this way in each time period T the the average power $P(kT_c)$ is obtained. This average power is obtained for each PWM control signal, fig.5, because the plant is a very slow process.

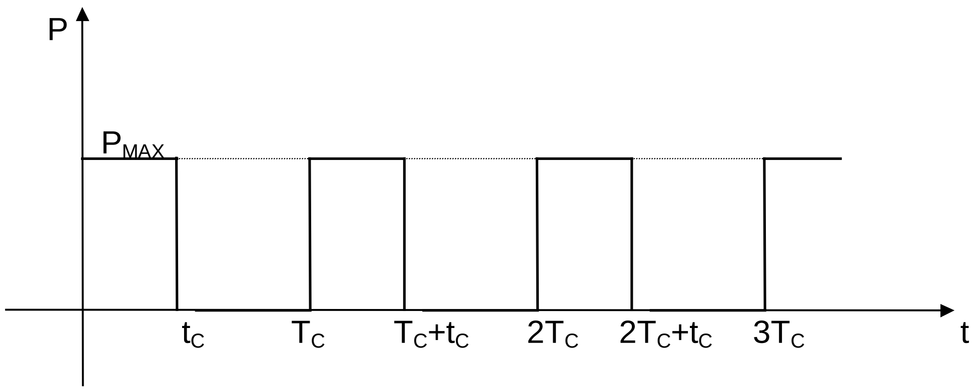

Fig. 5

By using the pulse width modulation for command value, fig.5 , the output average power $P(kT_c)$ is obtained by varying of the controller command time t_C. The command output average power $P(kT_c)$ is obtained for each time period T_c

$$P(kT_c) = \frac{t_c(kT_c)}{T_c} P_{MAX} \tag{1}$$

The command time t_c is obtained for each time period by digital controller. For the control system design the minimum, small, medium and maximum power PMIN, PMIC, PMED, PMAX are calculated to obtain the controlled process output. For the given reference value, for example r= 50 ^{0}C and for the given initial parameters, the transient process of the output value, the temperature in oven and de average power are calculated, fig.6.

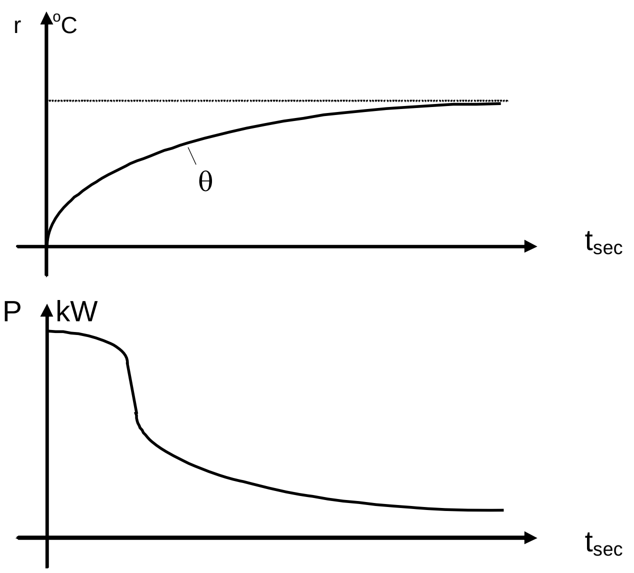

Fig. 6

The use of software to change the controller functionality makes a system based on a digital fuzzy controller very flexible. The digital controller offers the ability to add, eliminate or change any parameter in the system in order to meet new requirements or to optimize and calibrate the system. The presented control algorithm is similarly with a classic on/off control algorithm.

6. CONCLUSIONS

One of the advantages of PWM is that the signal remains digital all the way from the processor to the controlled device, no digital to analog converter is necessary. By keeping the signal digital, noise effects are minimized. Increased noise immunity is yet another benefit of choosing PWM over analog control, and is the principal reason PWM is can be used for communication and control systems. Switching from an analog signal to PWM can increase the length of a communications channel dramatically.

REFERENCES

1. Nitu C. (2000), *Intelligent techniques in ecology*, (in Romanian), Ed.Printech, Bucuresti
2. Computers, Communication and Mental Models, (1998) Edited by Donald L. Day and Diane K. Kovacs, Taylor&Francis
3. Nitu C., (2005) *Human Operator in Digital control Systems*, (in Romanian), Ed.Printech, Bucuresti