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A Fuzzy Controller for Digital Signals Processing

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Abstract. In some systems it needs to have digital signals with the possibility to fix the position of the rising edge or the falling edge into time period signal. In fact can be important to sample some signals in particular time instants to the inside period of signals. This paper shows the fuzzy control of delay times of a digital signal compared to another digital signal and the related experimental results. The objective of the paper is to introduce a new fuzzy logic control application and prove its advantages through comparison with classical methods.
Key words: fuzzy controller, digital signals

1. Introduction

The management of signals is important in a wide variety of applications, not only in telecommunications but also in scientific search projects. In astronomical observations, for example, it needs to supply signals with determined electrical characteristics to the detectors. These signals must have opportune voltage levels and they must supply the correct synchronism between signals. More just, it is necessary to consider the temporal relations between signals: instant of rising or falling edge, duration of high or low level voltage, the delay of a signal regarding other, and so on.

In this paper, we design a intelligent manager of digital signals, in which the control algorithm is implemented with the fuzzy logic. The intelligent digital architecture is implemented with pic16f876 microcontroller [1], a chip of the Microchip Technology Inc., that more it was adapted to our requirements.

The fuzzy control algorithm have two tasks: one is that of establish the time instant of commutation from low level to high level respect to rising edge of a specific input signal. The other task is that of to supply the duration of high logic level. In this mode we obtain a signal characterised by a rising edge and a time range in which it stays high, both controllable. These values are read by the fuzzy controller and in base to the characteristics wished, the controller adjusts the input signal. In output it will obtain a signal with the wished delay of the rising edge of signal output regarding rising edge of input signal. Moreover, the other parameter controlled and adjusted from controller is the time duration of high level signal output.

2. Fuzzy controller structure and input fuzzy sets

The design of a fuzzy controller requires more design decisions than usual, for example regarding rule base, inference engine, defuzzification, and data pre- and post processing.

Generally, the fuzzy controllers are being used in various control schemes. In this paper we consider the control scheme direct control [2], where the fuzzy controller is in the forward path in a feedback control system (Fig. 1).

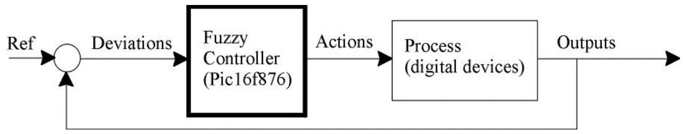

Figure 1 Block scheme of fuzzy controller

The process output, generated from specific digital devices opportunely connected, is compared with a reference, and if there is a deviation, the controller takes action according to the control strategy.

Our fuzzy controller is characterized by two inputs. The first is the delay of rising edge output signal respect to that of input signal. The second is the time range in which the signal it is maintained high. Both the variables are measured with the use of counters present into specific modules of 16f876.

These input variables must be converted in fuzzy variables by means of fuzzification. So, the first step is that of choose the input fuzzy sets and relative ranges. For both input variables we consider the same fuzzy sets. These variables must be divided into a set of fuzzy regions, which are given unique name called labels, within the domain of the variables. In our case we are used the labels: Very Negative (VN), Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM), Positive Big (PB), Very Positive (VP). Each of these sets is defined by the left and right limits of the set.

Elements of a fuzzy set are taken from a universe of discourse, the universe contains all elements that can come into consideration [3]. Even the universe depends on the context: in our case the universe of discourse is (-255,255) since the 16f876 works with 8 bits counters. These numbers represent the counter number for every input. Moreover, to each element is associated the membership function $\mu(x)$, where x is an element of discourse (Fig. 2).

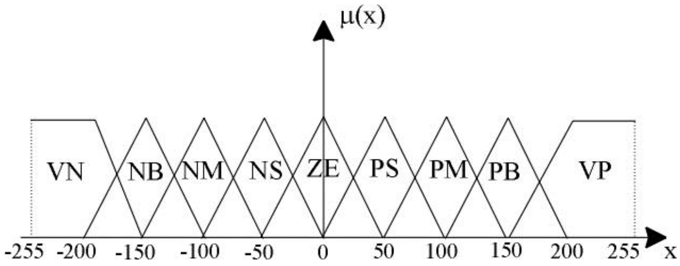

Figure 2 Membership functions for the input variables

The variable x represents the difference between the fixed value and measured value. To every value of x is assigned a grade of membership such that the transition from membership to non-membership is gradual rather than abrupt. This fact is obvious observing figure 2.

For the fuzzy outputs, we sub-divide the domain of the output in the following subdomains: VVL, (Very Very Low), VL (Very Low), L (Low), ML (Medium Low), M (Medium), MB (Medium Big), B (Big), VB (Very Big), VVB (Very Very Big). The difference respect to fuzzy input sets is that here we consider a particular membership function called singleton. The singleton is an impulse function, and is defined by simply assigning a single numeric value to each sub-domain of the output. In our case we choose this function because it represents the easiest way to describe the membership of the output to the fuzzy sub-sets defined. Besides the crisp output must be in the range 0-225, we define VVL=0, VL=32, L=64, ML=96, M=128, MB=160, B=192, VB=224, VVB=255 (Fig. 3).

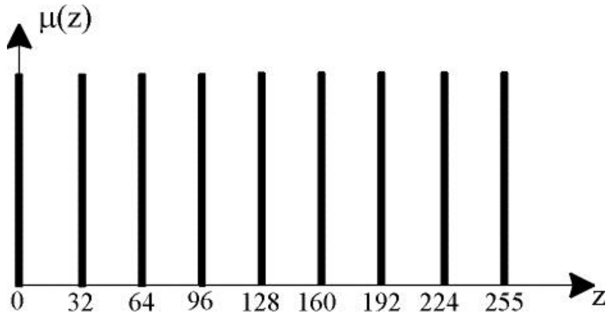

Figure 3 Output singletons

The output variable z shows the value that the fuzzy controller must send to particular digital devices to obtain the wished digital signal.

3. Fuzzification, rules evaluation and defuzzification

Once established fuzzy input sets and fuzzy output sets, the first step inside the controller is fuzzification, which converts each piece of input data to degrees of membership by a membership functions. In general, one membership value is calculated using the similar triangle principle, while the other is calculated from orthogonality of the membership function triangles. These values are needs for the rule evaluation.

In fact rule evaluation is the central element of a fuzzy logic control system. Basically a linguistic controller contains rules in the if-then format [4], but they can be presented in different formats. In our case the rules are:

1. If x is VN then *z* is VVL
2. If x is NB then *z* is VL
3. If x is NM then *z* is L
4. If x is NS then *z* is ML
5. If x is ZE then *z* is M
6. If x is PS then *z* is MB
7. If x is PM then *z* is B
8. If x is PB then *z* is VB
9. If x is VP then *z* is VVB

Finally, the final step that the fuzzy logic controller must carry out is to combine the fuzzy output into a crisp systems output.

Between the various methods to calculate the crisp output of the system we utilize the Centre of Gravity method (COD). For our application this method is expressed mathematically in the following equation: $z = \frac{\sum_{i=1}^{9} \mu_i(x) \cdot S_i}{\sum_{i=1}^{9} \mu_i(x)}$, where $\mu_i(x)$ is the degree of membership of variable x to fuzzy input set and S_i is the singleton value for the i-th rule. For example, for the rule 1 we have S_1=VVL=0.

4. Experimental results

In the evaluation board for pic16f876, the main devices are the retriggerable monostable multivibrators and digital potentiometers (Fig. 4).

The digital input signal is delayed either on high logic level or low logic level by the monostable multivibrators. The delay introduced from these devices depends by the values of capacitance and resistance respectively of capacitors and resistors them connect. The capacitance values are fixed while those of resistance can be changed driving the digital potentiometers.

The fuzzy algorithm provides for that the pic16f876 reads the two input variables. The first of these two values represents the time delay of rising edge output signal respect to the rising edge input signal. The microcontroller reads the number of counts about this time delay. The same speech is valid for the second input variable that represents the time duration of high logic level output signal.

From the computer we send, via serial port, two reference values to the pic16f876. In base to these reference values and to the read values before, the fuzzy controller provides two output values. In detail, the microcontroller executes the difference between the reference value and the read value before: this difference is the input variable x. So it processes the fuzzy algorithm and provides the z value that represents the word by to send to the digital potentiometer. In this mode we obtain the wished digital output signal.

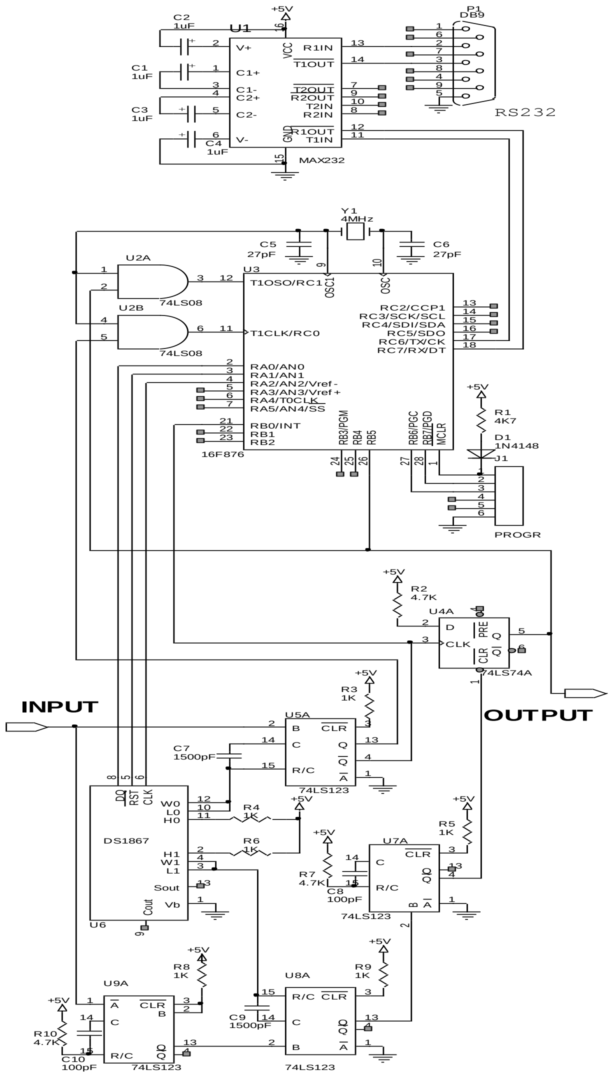

Figure 4 Detailed circuit of evaluation board

The fuzzy algorithm is implemented in assembler language of pic16f876. We underline that all the variables can assume values included between 0 and 255. In fact, our microcontroller works with registers to 8 bits. Moreover for the negative values of variables, we consider the absolute value.

Initially, there was the implementation of fuzzy algorithm in high level programming language. In our case the programming language used is the C language [5]. The platform it used is UNIX [6] and the compiler gcc. So we have tested to software level the correctness of the algorithm. Subsequently we have accomplished the algorithm in assembler language.

Since in pic16f876 instruction set there are not instructions for execute product and division between operands, we have utilized particular algorithms of iteration of sums and differences for implement this operations.

For generate the input signal we used a functions generator able of supply a digital signal with shape, frequency and amplitude selectable. In our experiments we used a square wave signal input with maximum frequency of 300KHz and amplitude 4V. Beyond this frequency some devices of the evaluation board, they don’t work correctly.

In figure 5 is showed the shape of delayed output signal regarding to the input signal. The wave in the top is the input signal, while the below wave shape represents the delayed output signal.

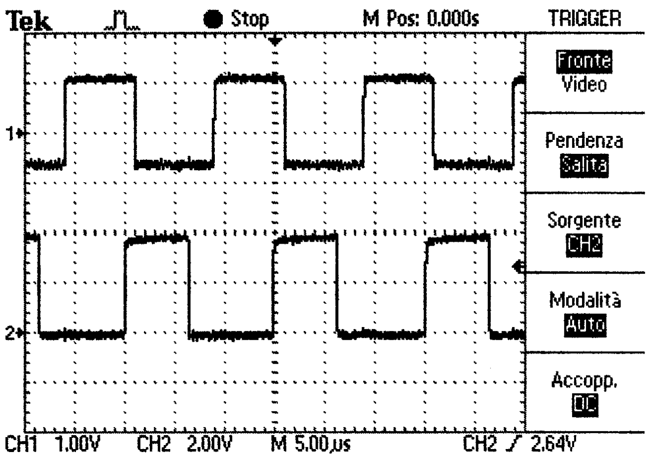

Figure 5 Delayed output signal

The two delays are fixed by two correspondents monostable multivibrators. In these the duration of the impulse depends from values of capacitance and resistance respectively of capacitors and resistors them connect [7]. In our case the value of capacitance is 1500pF and the resistance varies from 0 to 10Kohm. With the capacitance fixed to 1500pF and varying the resistance of digital trimmer in base to the results of the fuzzy algorithm, we obtain delays from 1us to 6us approximately.

5. Comparison between fuzzy and conventional controllers

In the automation sector the meant of word *control* indicates the set of the actions necessary to make vary in the wished manner a determined physical quantity. In our case the physical quantity to control is the time. In fact, the delay introduced from the multivibrators SN74LS123 it's given from the formula [7]:

$$t = K \cdot R \cdot C \cdot \left(1 + \frac{0.7}{R}\right).$$

The physical quantity time depends on the value of resistance R and on the value of capacitance C.

Fixed the capacitance, the controller drives the value of resistance R to obtain the wished value of t. In our case the value's resistance depends on number of steps to send to digital trimmer. Consequently it is necessary to found a correct agreement between input and output, that is between delay time and steps number. Using a classical controller, this agreement has less flexibility than a system based on fuzzy logic. In fact, in a fuzzy controller, is very easy to modify the extreme values of sub-domains of fuzzy input and output sets. Besides, the fuzzy control can be described simply as "control with sentences rather than equations". It's just this characteristic that makes preferable the use of a controller that works in fuzzy manner. The greater flexibility it is found in the programming. Whether for example we want to change the extreme values of sub-domains of the fuzzy sets (see figure 6), we will must to modify only about ten of parameters in the source code.

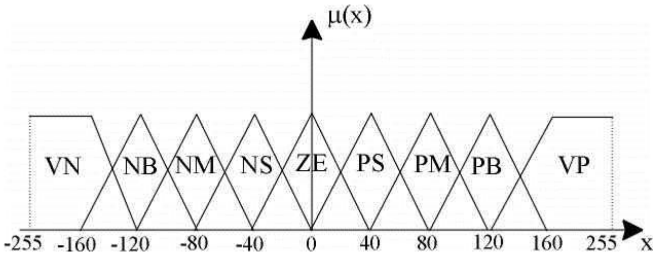

Figure 6 A change of sub-domains in the fuzzy input set

In the classical mode, instead, we will must to rebuild again the agreement input-output and the change it will have to be made value by value.

This advantage it creates some another: the greater speed to found the correct agreement between input and output. In fact, this agreement (delay time - step number) is found through attempts and the number of different possible combinations inputs/outputs, in a fuzzy controller, is certainly lower than a classical controller.

6. Conclusions

This fuzzy controller has turned out useful for the management of control signals of IR-detectors [8]. In fact, for the operation of these devices, it is necessary to supply some bias signals. In this context is important the sample, near to a specific time instant, of voltage signals to the output of detector. This time instant can be easy controlled and so fixed on the entire pixel time [8]. This facility with which it turns out possible to control the sampling instants, it is good reason for implementing this method in search projects.

With our experimental instrumentation it has been possible to process digital signals of frequency until 300KHz. This method can be also applied to devices with a advanced dynamics than those of figure 4. In this way it will be possible the management of digital signals of frequency greater than 300KHz.

The advantages of this fuzzy controller compared to classical controllers, can be exploit in the astronomical technologies, in particular for the sample of IR-detectors output signals in which it’s important to sample inside the pixel time.

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