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Memory Organization for a Fuzzy Controller.

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Abstract

Fuzzy Logic based Control Theory has gained much interest in the industrial world, thanks to its ability to formalize and solve in a very natural way many problems that are very difficult to quantify at an analytical level.

This paper shows a solution for treating membership function inside hardware circuits.

The proposed hardware structure optimizes the memories size by using particular form of the vectorial representation.

The process of memorizing fuzzy sets, i.e. their membership function, has always been one of the more problematic issues for the hardware implementation, due to the quite large memory space that is needed. To simplify such an implementation, it is commonly [1,2,8,9,10,11] used to limit the membership functions either to those having triangular or trapezoidal shape, or pre-definite shape. These kinds of functions are able to cover a large spectrum of applications with a limited usage of memory, since they can be memorized by specifying very few parameters (height, base, critical points, etc.). This however results in a loss of computational power due to computation on the medium points. A solution to this problem is obtained by discretizing the universe of discourse **U**, i.e. by fixing a finite number of points and memorizing the value of the membership functions on such points [3,10,14,15]. Such a solution provides a satisfying computational speed, a very high precision of definitions and gives the users the opportunity to choose membership functions of any shape. However, a significant memory waste can as well be registered. It is indeed possible that for each of the given fuzzy sets many elements of the universe of discourse have a membership value equal to zero. It has also been noticed that almost in all cases common points among fuzzy sets, i.e. points with non null membership values are very few. More specifically, in many applications, for each element **u** of **U**, there exists at most three fuzzy sets for which the membership value is not null [3,5,6,7,12,13]. Our proposal is based on such hypotheses. Moreover, we use a technique that even though it does not restrict the shapes of membership functions, it reduces strongly the computational time for the membership values and optimizes the function memorization.

In figure 1 it is represented a term set whose characteristics are common for fuzzy controllers and to which we will refer in the following. The above term set has a universe of discourse with 128 elements (so to have a good resolution), 8 fuzzy sets that describe the term set, 32 levels of discretization for the membership values. Clearly, the number of bits necessary for the given specifications are 5 for 32 truth levels, 3 for 8 membership functions and 7 for 128 levels of resolution. The memory depth is given by the dimension of the universe of the discourse (128 in our case) and it will be represented by the memory rows.

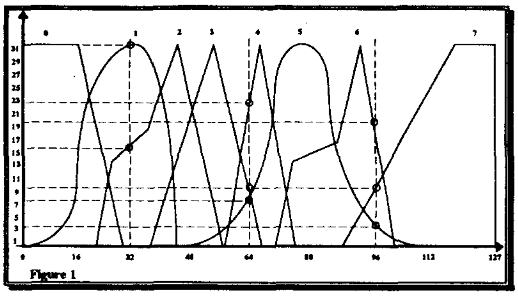
Figure 1

The length of a word of memory is defined by:

$$Length = nfm \bullet (dm(m) + dm(fm))$$

Where:

- *nfm* is the maximum number of non null values in every element of the universe of the discourse,
- *dm(m)* is the dimension of the values of the membership function *m*,
- *dm(fm)* is the dimension of the word to represent the index of the highest membership function.

In our case then *Length=24*. The memory dimension is therefore **128*24** bits. If we had chosen to memorize all values of the membership functions we would have needed to memorize on each memory row the membership value of each element. Fuzzy sets word dimension is **8*5** bits. Therefore, the dimension of the memory would have been **128*40** bits.

Coherently with our hypothesis, in fig. 1 each element of universe of the discourse has a non null membership value on at most three fuzzy sets.

Focusing on the elements 32,64,96 of the universe of discourse, they will be memorized as follows:

32 =[31,1,15,2,0,0]
64 = [23,4,9,3,7,5]
96 = [19,6,9,7,3,5]

The computation of the rule weights is done by comparing those bits that represent the index of the membership function, with the word of the Program Memory. The output bus of the Program Memory (µCOD), is given as input a comparator (Combinatory Net). If the index is equal to the bus value then one of the non null weight derives from the rule and it is produced as output, otherwise the output is zero (fig. 2).

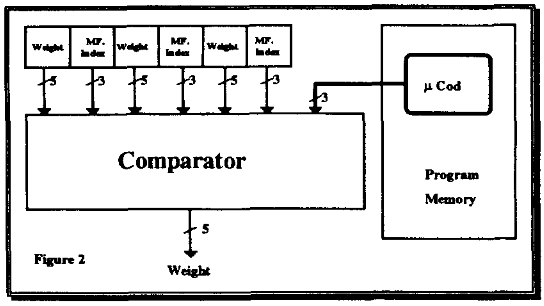

Figure 2

It is clear, that the memory dimension of the antecedent is in this way reduced since only non null values are memorized. Moreover, the time performance of the system is equivalent to the performance of a system using vectorial memorization of all weights.

The dimensioning of the word is influenced by some parameters of the input variable. The most important parameter is the maximum number of membership functions **(nfm)** having a non null value in each element of the universe of discourse. From our study in the field of fuzzy system, we see that typically **nfm ≤ 3** and there are at most **16 membership function**. At any rate, such a value can be increased up to the physical dimensional limit of the antecedent memory. A less important role in the optimization process of the word dimension is played by the number of membership functions defined for each linguistic term. The table below shows the request word dimension as a function of such parameters and compares our proposed method with the method of vectorial memorization [10].

Non null values	Mem. Functions	Proposed system	Vector System
2	8	16	40
2	16	18	80
2	32	20	160
3	8	24	40
3	16	27	80
3	32	30	160
4	8	32	40
4	16	36	80
4	32	40	160

Summing up, the characteristics of our method are:

- Users are not restricted to membership functions with specific shapes.
- The number of the fuzzy sets and the resolution of the vertical axis have a very small influence in increasing memory space.
- Weight computations are done by combinatorial network and therefore the time performance of the system is equivalent to the one of the vectorial method.
- The number of non null membership values on any element of the universe of discourse is limited. Such a constraint is usually non very restrictive since many controllers obtain a good precision with only three non null weights.

The method here briefly described has been adopted by our group in the design of an optimized version of the coprocessor described in [10].

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