The Eurasia Proceedings of Science, Technology,
Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2023

Volume 24, Pages 257-262

IConTech 2023: International Conference on Technology

User-Selected Sets of Algorithmic Implementation of Fuzzy Processing Subsystem for Embedded Intelligent Control Systems

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Abstract: Embedded intelligent control systems (EICS) have been used in a wide range of tasks involving the adaptive control of technical objects and processes. For the hardware implementation of EICS, developers actively use function-oriented microcontrollers, that aimed to be the effective implementation of control algorithms, including adaptive and intelligent control. Embedded control systems based on the concept of fuzzy set theory have recently been developed for specific individual control operations, allowing more efficient implementation of complex object control algorithms. This paper approaches the study of the different implementation of control algorithms in embedded microcontrollers based on fuzzy sets theory to result in reduced hardware area and complexity, high operating speed, and adaptability to various applicable domains. It shows that the performance of fuzzy computing specialized in embedded systems has significantly increased and makes possible a huge scope for further improvement of the implementation of fuzzy control algorithms at the hardware level.

Keywords: Embedded control system, MCS-51, Control algorithms, Fuzzy sets, Fuzzy computation

Introduction

The embedded control systems based on the methods of fuzzy logic have been extensively used in control engineering, consumer electronics, house hold appliances, data processing, decision making systems, expert and signal processing systems including in the tasks of managing objects of marine engineering (Juuso,2004). A biggest advantage of the fuzzy logic is the easy modelling of human behaviour; it directly maps the human inference system to the fuzzy *if – then* rules, which are easily understood by the human beings. Just as fuzzy logic can be described simply as "computing with words rather than numbers", fuzzy control can be described simply "control with sentences rather than equations" (Togai & Watanabe,1986). The first hardware realization of a fuzzy logic processor was done by Togai and Watanabe. Nowadays the intelligent control systems built on the basic concept of the theory of fuzzy sets, have recently become more popular, allowing more efficiently to implement complex object control algorithms (Fons et al.,2006). It should be noted that current using fuzzy control systems are built for general-purpose computing machines and programmable fuzzy processors designed to store and process fuzzy rules (Evmorfopoulos & Avaritsiotis, 2002). Since the mathematical apparatus of the fuzzy sets is quite varied from the view of different theories, the algorithmic implementations for fuzzy computation processes are much diverse to achive the user's desires.

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

In this paper, we concentrate an analyze in different algorithmic implementations of fuzzy processing subsystem based on a function-oriented microcontroller with bit manipulation through low level language aimed to be the effective implementation of control algorithms, including adaptive and intelligent control. It is possible to increase the productivity of fuzzy information processing processes, which are specialized on MCS-51 that support the integrated implementation of fuzzy control algorithms for embedded intelligent control systems.

Analysis of Structural and Algorithmic Operation in Fuzzy Computation System

The fuzzy computing subsystem solves the problems of adaptive and intelligent control based on the theory of fuzzy sets, forming the values of the ultrasonic setpoints parameters for the control subsystem by generalized information about the state of the control object (Niu et al., 2019). As shown in (Fig.1) the number of input and output variables used triggered terms corresponding to each linguistic variable from the table of fuzzy transformation rules (Fons et al.,2006). Since there is a number of stages in fuzzy computation based on microcontroller, that uses the resources of the main controller processor, which leads to automatic suspension for algorithmic calculations running in the fuzzy subsystem. It should also be noted that, the current existing technical solutions do not provide the possibility of specifying arbitrary membership functions, allowing only their piecewise linear form, which negatively affects the achievable accuracy of calculations. Thus, the problem of improving the performance of embedded intelligent control systems is approached by developing an embedded mathematical apparatus for describing membership terms and rule base, and ensure efficient (in the typical sense of intelligent control) calculation of fuzzy processing subsystem with bit manipulation based on MCS-51. This approach manages to describe the arbitrary form of various membership terms with the higher possible accuracy. The inevitable task for the algorithmic and schematic implementation of fuzzy computing subsystem using in this subjected area of embedded control system will be considered in this paper.

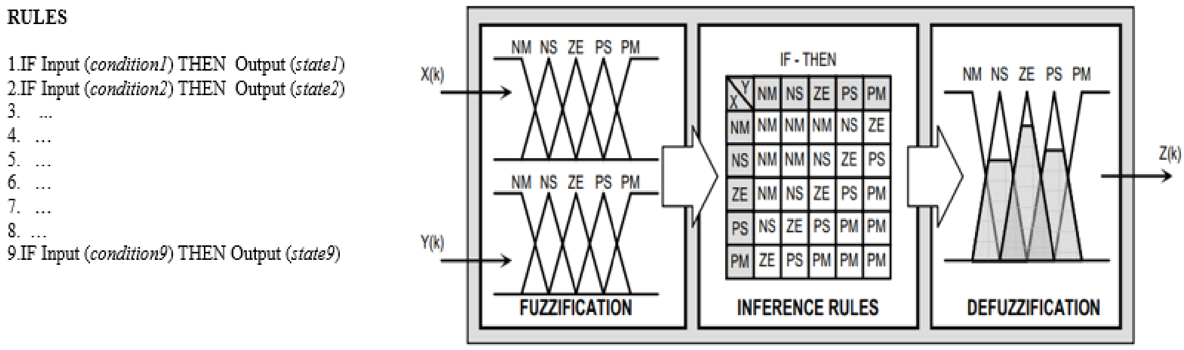


Figure1.General fuzzy computation system (Niu et al., 2019)

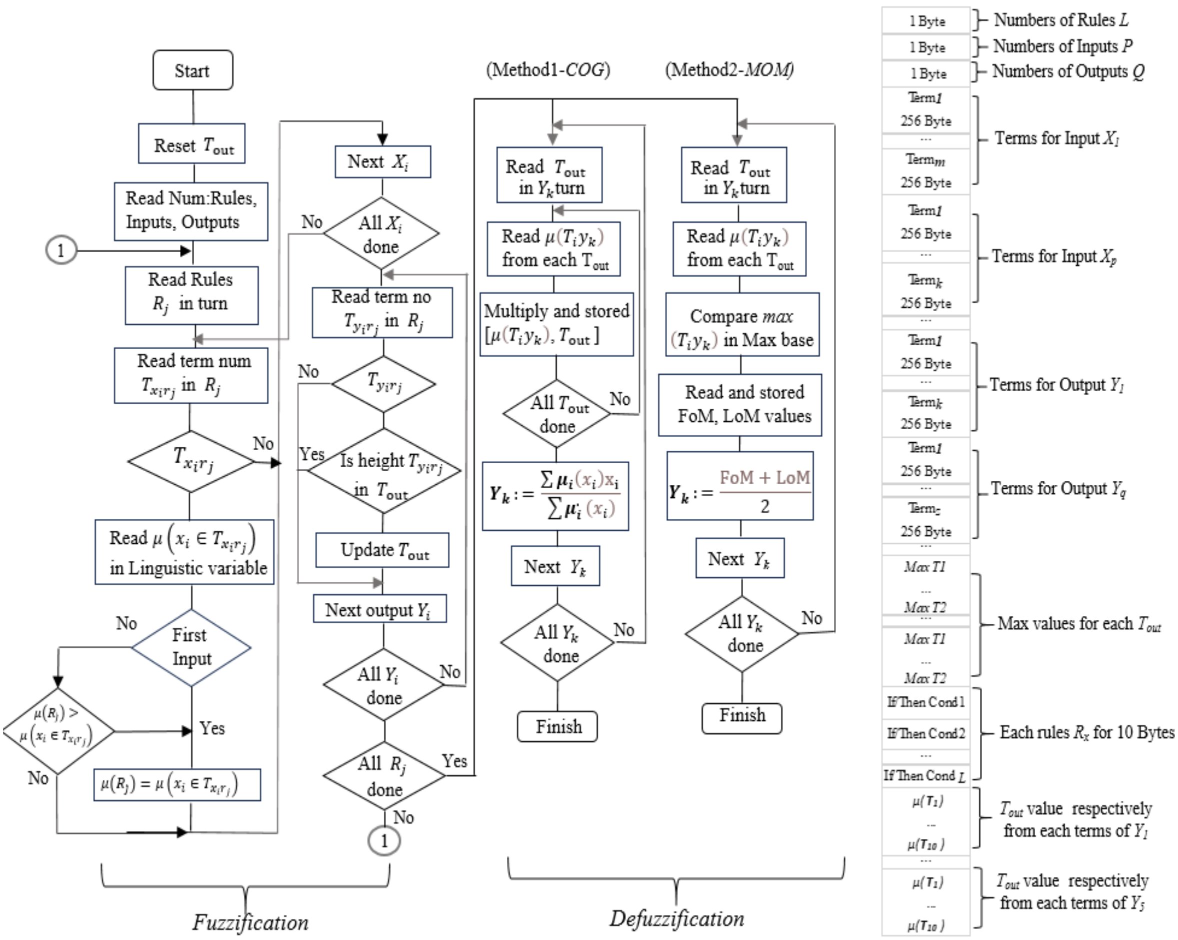
Algorithmic Implementation for Improving Fuzzy Computation Performance

According to the improving task mentioned above, we have considered to effectively organize algorithmic structure and memory organization in single chip microcontroller that support efficient fuzzy computation. There are many priorities in developing a new structural organization of fuzzy computing subsystems and the principles of their functioning :1) effective implementation of the proposed high-speed fuzzy data processing algorithm, 2) significant expansion of the variety of hardware-implemented control systems with fuzzy information processing, 3) ensuring a high rate of fuzzy data processing, which is performed in parallel with the execution of the program of the control processor(Vassiliev et al., 2017). Thus,a vital need in developing new algorithms for the functioning fuzzy computation is to develop effective methods to support the execution of fuzzy operations in the sense of minimizing computing time and memory demands. The most common using algorithms for fuzzy information processing include Sugeno, Larsen and Mamdani algorithms (Togai & Watanabe, 1986). The last one has the highest accuracy but it is most demanding on the amount of allocated computing resources (Mamdani,1974). To implement the most high-speed algorithm proposed in this paper (Fig. 2(*a*)) uses the method of "look-up tables", which operates with graphs specified by a set of vector arrays and a rule base specified by a table. In order to assemble compact memory organization, suggest to assign memory locations as in (Fig. 2(*b*)). The terms are stored as an array of membership degree values, ordered in ascending order by a clear variable. In this case, the range of membership degree values [0...1] is equivalent to the range [0...255]; for example, the value 0.5 will be equivalent to code 128, the value 1 will be 255 (Fig.3*(a)*).

When fuzzification and defuzzification performing, the corresponding term array is addressed by the value of the input variable, and return the linguistic value to the term belonging of this variable.

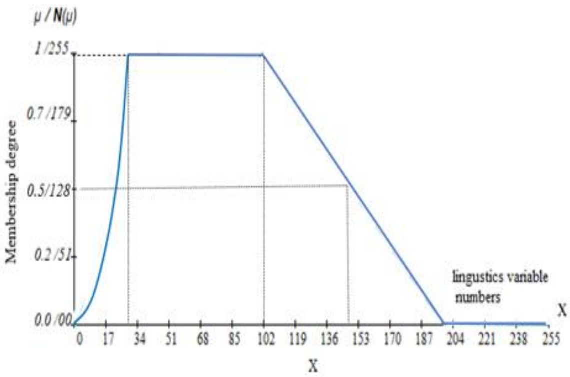
The rule base is set by the table in which number of rows corresponds to the number of rules. Each row consists of "input" and "output" columns (Fig.3*(b)*). The input columns describe the term numbers of the input variables involved in the formation of the conditions of the rule, and the output columns describe the numbers of outputs calculated if the conditions of this rule are triggered. The input and output cells do not depend each others, and the example rule structure R_5 is presented as follow:

$$\text{IF } (X_2 \in T_{x2r5}) \text{ and } (X_5 \in T_{x5r5}), \text{ THEN } (Y_1 \in T_{y1r5}), \text{ as well } (Y_4 \in T_{y4r5}) \qquad (1)$$



(a) *(b)*

Figure 2. *(a)* Algorithmic structure of fuzzy computation subsystem, *(b)*Memory organization for fuzzy computation



(a)

	IF					THEN				
	X_1	X_2	X_3	X_4	X_5	Y_1	Y_2	Y_3	Y_4	Y_5
R_1	T_{x1r1}		T_{x3r1}			T_{y1r1}				T_{y5r1}
...										
R_5		T_{x2r5}			T_{x5r5}	T_{y1r5}			T_{y4r5}	
...										
R_n			T_{x3rn}		T_{x5rn}		T_{y2rn}			T_{y5rn}

(b)

Figure 3. *(a)* General membership term, *(b)* Rule base organization

Such a structural organization of the fuzzy knowledge base provides a significant increase in accuracy and productivity compared to previous known solutions, since it allows you to operate with membership functions of an arbitrary type. At the same time, the fuzzification speed does not depend on the type of membership function and is the maximum achievable (since the procedure for calculating the value of the membership function is reduced by indexing a given cell of a one-dimensional array). The absolute values of the performance gain are obviously determined by the use of the algorithmic implementation with selected deffuzification methods. In the proposed implementation, the calculation methods are used the widely used methods "Center of Gravity" and "Middle of Maxima" presented in equations (2) and (3):

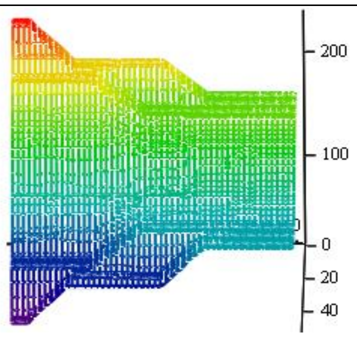
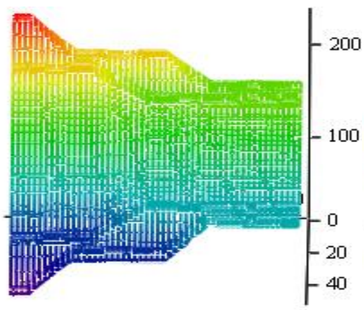
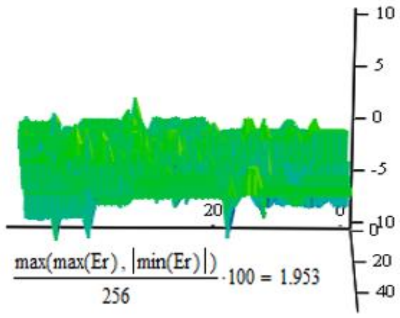
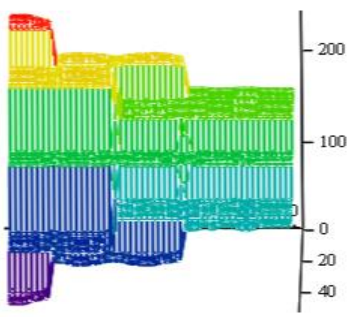
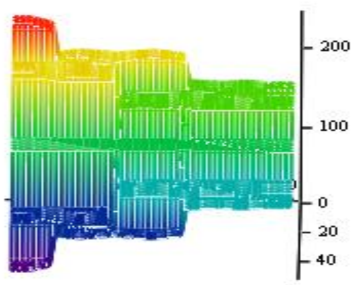
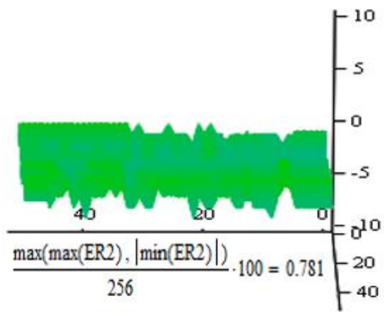
$$Y_k := \frac{\sum \mu_i(x_i) x_i}{\sum \mu_i(x_i)} \; , i \in 1,2,3,\ldots,k \tag{2}$$

$$Y_k = \frac{\sum_{x \in M}(x_i)}{|M|} \; , i \in 1,2,3,\ldots,k \tag{3}$$

Experimental Analysis of Algorithmic Implementation

As Vassiliev et al. (2017) explained, the fuzzy information processing subsystem can be described and calculated in the low-level programming language to approach a simple structure and high speed general-purpose fuzzy logic microcontroller. It is intended to communicate directly with specific hardware/software resources on the MCS-51 device. In this proposed implementation, MCS-51 is set with 12 MHz internal bus frequency for processing up to 25rule base through 2 inputs and 1 outputs properly. The data collections of the statistical results and visual experiments are carried out by means of Mamdani Inference System and Shell51 developed by the author (Vassiliev,2017) of this paper. To analyze the accuracy of the developed fuzzy computation,we represent different algorithmic implementations and compare to corresponding simulation results.

Table 1. Analyze developed fuzzy computation system

Data surface from MATLAB	Results from MCS-51	Differentiation (%)
		
	(COG-Method)	
		
	(MOM-Method)	

It can be seen from the table that the different implementation results are quite uniform compared to MATLAB data surface simulation. It indicates that the developed information subsystem strategy can be achieved by using function-oriented microcontroller with bit manipulation through look-up table algorithm based on MCS-51 device. Additionally this analyze shows that developed fuzzy subsystem with low level language harmonically engaged with commercial simulation results without losing the generality of actual processing characteristics.It makes advantage of increasing productivity in certain control system that needs high operating speed and reduced complexity to a compact design.

Conclusion

This paper presents a methodological principals of developing fuzzy computing subsystem that taking into account a clear tradeoff in the development phases of fuzzy coprocessor and the calculation accuracy supported for the low cost and compact implementation design. The developed subsystem with bit manipulation makes possible to meet high speed real time requirements, reducing the intense resource of fuzzy information converters. It has shown that there is a huge scope for further improvement in these fuzzy systems at hardware level to reduce the complexity of analysis and synthesis in co-processor and their performance can be improved further by designing optimized architectures.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Technology (www.icontechno.net) held in Antalya/Turkey on November 16-19, 2023.

References

Ascia, G., Catania, V., & Russo, M. (1999). VLSI hardware architecture for complex fuzzy systems. *IEEE Transactions on Fuzzy Systems*, *7*(5), 553–570.

Barrett, S. F., & Magleby, D. B. (2004). Embedded systems: Design and applications with the 68HC12 and HCS12. Retrieved from https://www.amazon.com/Embedded-Systems-Design-Applications

Evmorfopoulos, N., & Avaritsiotis, J. (2002). An adaptive digital fuzzy architecture for application-specific integrated circuits. *Active and Passive Electronic Components,25*(4), 289-306.

Fons, F., Fons, M., & Cantó, E. (2006). System-on-chip design of a fuzzy logic controller based on dynamically reconfigurable hardware. *International Transactions on Systems Science and Applications, 2,* 191–196. Retirved from https://dblp.uni-trier.de/db/journals/itssa/itssa2.html

Juuso, E. (2004). Integration of intelligent systems in development of smart adaptive systems. *International Journal of Approximate Reasoning*, *35*(3), 307–337.

Gabrielli, A., & Gandolfi, E. (1999). A fast digital fuzzy processor. *IEEE Micro*, *19*(1), 68–79.

Johnson, J., Madhumitha, G., Yousuf, N., & Harikrishnan, S. (2016). Design, development and fuzzy logic based control of a remotely operated underwater vehicle. *International Conference on Robotics and Automation for Humanitarian Applications (RAHA).*

Kandel, A., & Langholz, G. (1997). *Fuzzy hardware: Architectures and applications*. In Kluwer Academic Publishers eBooks. Retrieved from http://ci.nii.ac.jp/ncid

Lee, C. (1990). Fuzzy logic in control systems: fuzzy logic controller. I. *IEEE Transactions on Systems, Man, and Cybernetics*, *20*(2), 404–418.

Mamdani, E. (1974). Application of fuzzy algorithms for control of simple dynamic plant. *Proceedings of the Institution of Electrical Engineers*, *121*(12), 1585.

Minghui, W., Yongquan, Y., & Bi, Z. (2005). Ship steering system based on fuzzy control using real-time tuning algorithm. *ICITA 2005, 1*.

Niu, J., Wang, Z., Zhang, P., Zhang, B., & Xu, C. (2019). Research on implementation method of fuzzy logic control based on MCU. *Journal of Physics: Conference Series*, 1345.

Ross, T. J. (1994). Fuzzy logic with engineering applications. Retrieved from http://202.159.8.148:8001/~digilib/index.php?

Togai, M., & Watanabe, H. (1986). Expert system on a chip: an engine for real-time approximate reasoning. *IEEE Expert*, *1*(3), 55–62.

Tran, T. A., & Haidara, G. (2019). A research on marine diesel engine speed controller by fuzzy logic control theory based on experimental investigation. *Journal of Mechanical Engineering Research and Developments*. *42*(2), 18-26.

Vassilev, A., Ivanova, T. Y., Cabezas, T. D. F., & Sadin, Y. D. (2015). Design of function-oriented microcontrollers on equipment of programmable logic integrated circuits for embedded systems. *Automatic Control and Computer Sciences. 49*, 404-411.

Vassiliev, A. E. (2011a, June 17). *RU2477525C2* - Microcontroller with hardware fuzzy variable structure calculator - *Google Patents*. Retrieved from https://patents.google.com/patent/RU2477525C2/ru

Vassiliev, A., & Giganova, V. I. (2014). Networks of elementary fuzzy solvers for synthesizing and analyzing fuzzy data processing and control Systems. *Proceedings of the Russian Academy of Sciences*. *2014*(6), 34–44.

Vassiliev, A.E., Vasilyanov, G. S., Cabezas, T. D. F., Pereverzev, A. E., & Nguyen, B. H. (2017). Hardware implementation of high-performance fuzzy computing on programmable logic integrated circuits, *Радиотехника и электроника Радиотехника и Электроника*, *12*, 1243–1256.

Watanabe, H., Dettloff, W., & Yount, K. M. (1990). A VLSI fuzzy logic controller with reconfigurable, cascadable architecture. *IEEE Journal of Solid-State Circuits*, *25*(2), 376–382.

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To cite this article:

Vassiliev, A. E., Shine, H., Htet, Y.M. & Karpenko, V. A. (2023). User-selected sets of algorithmic implementation of fuzzy processing subsystem for embedded intelligent control systems: *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 24,* 257-262.