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An Arduino FIST Evaluation for Fuzzy System Conversion from Matlab to Arduino

Jose Eleazar Peralta-Lopez, David Lazaro-Mata,
Jose Alfredo Padilla-Medina, Francisco Javier Perez-Pinal,
Alejandro Israel Barranco-Gutierrez

Tecnológico Nacional de México en Celaya,
Departamento de Electrónica,
Mexico

israel.barranco@itcelaya.edu.mx

Abstract. Today, the Arduino micro-controller is widely used because many engineers have contributed to the manufacture of different solutions that are documented and freely shared on the Internet. This digital circuit has pre-loaded typical functions that make it easy to use. Proof of this is the compiler built by the group of programmers from makeproto.com, they managed to build a translator from Matlab code to Arduino code which we put to the test. The purpose of this work is to quantitatively evaluate the implementation of a fuzzy system on Arduino from its Matlab design. The example presented is the implementation of a Mamdani-type fuzzy system to infer the tip given to a restaurant because is a very typical problem in fuzzy systems. The fuzzy system implementation on Arduino give a minimal numerical difference between systems but highlighted rapid fuzzy system implementation from Matlab designer.

Keywords: Arduino, fuzzy system, FIST, code translator.

1 Introduction

Currently, the electronics community has seen a fast development in the number and diversity of applications of Fuzzy Logic, ranging from consumer integrated circuit technology and industrial process control to decision support systems and financial trading.

These applications range from Navigation Control [1], ambiguity and noise diminishing from biometric security applications [2], stabilization of continuous-time the design of saturated sampled-data Parallel-Distributed Compensation controllers, composed by the estimation of the closed-loop domain of attraction [3], to voltage compensation in DC-DC converters [4]. So, the optimization of the implementation of fuzzy systems in embedded circuits has increased significance.

This leads us to evaluate their energy feeding, size, weight, speed of response and implementation time. There are also other implementations of fuzzy systems on raspberry pi, FPGA, typhon HIL or PCs [5, 6].

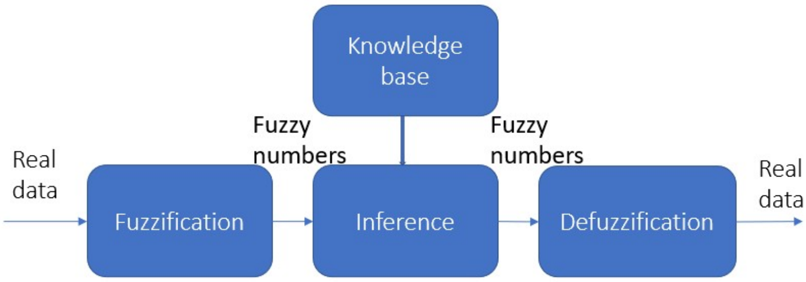

Fig 1. General structure of fuzzy systems.

Fig. 2. Arduino Pro-Mini.

Fuzzy systems have become relevant for being one of the artificial intelligences methods that best compete with neural networks due to the explainable of their architecture and the easy understanding of their working ranges [7].

Fuzzy systems mainly consist of four subsystems: fuzzification, knowledge base, inference engine, and defuzzification [8]. Fuzzification consists of converting sharp or real numbers into fuzzy numbers, in order to convert from the numerical world to the linguistic or ambiguous world.

The knowledge base contains the inference rules that the inference engine executes based on the input values. Finally, the defuzzification subsystem converts fuzzy numbers to sharp or real numbers as shows Fig. 1.

By other hand, Arduino free hardware boards are increasingly used for the development of control programs, especially academic level programs. But there are areas that have begun to be addressed. One of these areas is the implementation of fuzzy systems. Being able to implement this type of system on a board like the one mentioned brings advantages over other platforms due to its portability and low cost, which increases the advantage of using free hardware and software [9].

2 Materials and Method

In this work we basically use three tools: the Matlab fuzzy systems designer, the Matlab to Arduino compiler (Arduino FIST) and an Arduino Pro-Mini microcontroller. The group of programmers from http://www.makeproto.com managed to build a translator from Matlab code to Arduino code (an extension of "c" language) which we put to the test in this article [10].

The example presented is the implementation of a Mamdani-type fuzzy system to infer the tip given to a restaurant because is a very typical and basic problem in fuzzy systems.

2.1 Fuzzification

The definition on fuzzy system works as follow: Functions (1) to (5) show the description of different variables used. F represents qualification for "food", variable S represents "Service". Specifically, RF means "Rancid food", DF means "Delicious food", PS represents "Poor service", GS is for "Good service" and ES for "Excellent service":

$$RF = \begin{cases} 1 & 0 \leq f < 1, \\ \dfrac{3-f}{2} & 1 \leq f < 3, \\ 0 & \text{otherwise}, \end{cases} \tag{1}$$

$$DF = \begin{cases} 0 & \text{otherwise}, \\ \dfrac{f-7}{2} & 7 \leq f < 9, \\ 1 & 9 \leq f < 10, \end{cases} \tag{2}$$

$$PS = \begin{cases} \dfrac{3-S}{3} & 0 \leq f < 3, \\ 0 & \text{otherwise}, \end{cases} \tag{3}$$

$$GS = \begin{cases} \dfrac{S-2}{3} & 2 \leq f < 5, \\ \dfrac{8-S}{3} & 5 \leq f < 8, \\ 0 & \text{otherwise}, \end{cases} \tag{4}$$

$$ES = \begin{cases} \dfrac{S-7}{3} & 7 \leq f < 10, \\ 0 & \text{otherwise}. \end{cases} \tag{5}$$

2.2 Knowledge Base and Inference Engine

In order to develop the knowledge base or rules of the system, the maximum and minimum fuzzy operators are used. These operators are equivalent to the logical operators OR and AND respectively.

The maximum operator compares two membership degrees of both inputs and assigns the maximum value to the defuzzifier, the minimum operator compares two membership degrees equally and the minimum value between both is assigned to the output. In the case of this fuzzy system, the rules implemented are the following:

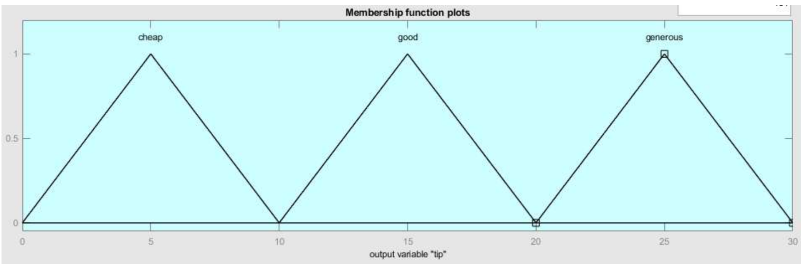

Fig. 3. Fuzzy output membership functions.

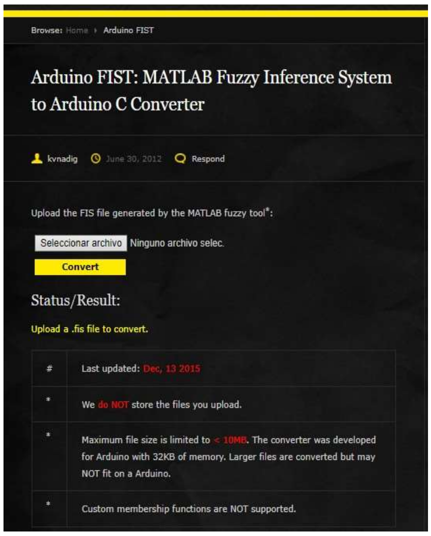

Fig. 4. Web application to convert the fuzzy system designed in Matlab to its Arduino version.

1 IF food is rancid or service is poor THEN tip is cheap.
2 IF service is good THEN tip is good.
3 IF food is delicious or service is excellent THEN tip is generous.

2.3 Defuzzification

In this case, the defuzzification is done by calculating the centroid of the figure resulting from applying different levels to each of the membership functions of the output, as can be seen in the equation (6) and Fig. 3, where the variable TIP is the output and the variables A_{tch}, A_{tgo} and A_{tge} represent the areas of the membership functions of the cheap tip, good tip and generous tip, respectively, contained from 0 to the degree of membership of each one.

The calculation of the area can be done with numerical methods or with approximations such as the one shown in [9]:

$$TIP = \frac{5 * A_{tch} + 15 * A_{tgo} + 25 * A_{tge}}{A_{tch} + A_{tgo} + A_{tge}}. \qquad (6)$$

Table 1. Fuzzy systems outputs in Matlab and Arduino with its absolute difference.

Food	Service	Matlab	Arduino	Error
0	0	5	5	0
0	2	5	5	0
0	3	8.58	8.58	0
0	5	10	10	0
0	7	8.58	8.58	0
0	8	12.10	12.14	0.04
0	10	15	15	0
2	0	5	5	0
2	2	5	5	0
2	3	9.26	9.26	0
2	5	10.7	10.72	0.02
2	7	9.26	9.26	0
2	8	13.5	13.57	0.07
2	10	16.4	16.43	0.03
5	0	5	5	0
5	2	5	5	0
5	3	15	15	0
5	5	15	15	0
5	7	15	15	0
5	8	25	25	0
5	10	25	25	0
8	0	13.6	13.57	0.03
8	2	16.5	16.49	0.01
8	3	20.7	20.74	0.04
8	5	19.3	19.28	0.02
8	7	20.7	20.74	0.04
8	8	25	25	0
8	10	25	25	0
10	0	15	15	0
10	2	17.9	17.82	0.08
10	3	21.4	21.42	0.02
10	5	20	20	0
10	7	21.4	21.42	0.02
10	8	25	25	0
10	10	25	25	0

2.4 From Matlab code to Arduino

The fuzzy system is designed in the Fuzzy Logic Designer, it is saved as a .fis file, it is uploaded to the application and it gives us a .zip file that contains the c-arduino code and another .h file that together work to execute the system previously designed.

In the Fig 4 it shows the Web application to upload the fuzzy system designed in Matlab to get its Arduino version.

3 Results

Using the “Arduino FIST” web application, 304 lines of C-Arduino code were obtained and its h file header. Table 1 shows a set of different inputs to the fuzzy system implemented in Matlab and the other implemented in Arduino, as well as the difference between both. In order to compare the results and the quality of the implementation.

4 Discussion and Conclusions

It is concluded that the conversion of fuzzy systems from Matlab to Arduino using the “Arduino FIST” web tool produces results almost of the same quality as the MATLAB Fuzzy Toolbox.

With a maximal error of 0.08 for the particular case where the food was 10 and the service 2. It is convenient highlight the advantages of portability, low power consumption and low cost of Arduino and a Matlab to Arduino (”C”) conversion speed of less than one second.

An improvement to this proposal could be the implementation of the accuracy improvement for numbers less than tenths of a unit. In other works, such as [11], this tool has been analyzed qualitatively, while in this document we present a quantitative analysis to observe the order of error that the fuzzy system implemented in Arduino gives us. For this case the maximum error in an estimate was 0.08.

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