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Temperature Control of Drying Chambers with Fuzzy Logic Algorithm for Common Microcontroller Systems

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Abstract: The fuzzy logic control algorithms are relatively new direction in the field automatic control systems. These algorithms are similar to the thinking style of humans and give more flexibility over controlled parameter than classical systems theory control methods, which are limited in decisions to discrete set of the measured parameters. The fuzzy logic, however can be extended for any type of controlled parameters, described in usual common words, for example, "not so high", "neither high, nor low" and so on. Each of these statements defines the percentage of output parameters.

The fuzzy logic algorithm in this article is used for temperature control of the drying chambers and has been successfully implemented with usual microcontroller. The device has been tested in a series of experiments and the article contains conclusions of the results of such testing.

Keywords: Dying chamber, fuzzy logic, microcontroller system, temperature control.

1. Introduction

The concept of fuzzy set has been created as a "dissatisfaction with mathematical models of classic systems theory, which requires to achieve artificial accuracy inappropriate for many of real world systems, especially those involving humans" [1]. The use of fuzzy logic makes it possible to create control algorithm with simple common expressions of "If-then" type, or linguistic rules. Because of use of the simple and plain construction of the algorithm, fuzzy logic devices are widely used in different areas, such as, control of technological processes, control of transport, diagnostics, exchange prediction, image recognition and other systems, which require to model decision taking in the way that is similar for human [1-5].

The present article describes development of the simplest algorithm with fuzzy logic for a temperature regulation of industrial drying chamber with ordinary microcontroller. Such implementation must control temperature regardless of the heating environment. That means, in simple words, the algorithm should be universal and be capable of temperature control for any drying chamber regardless of its size and model [2-3].

2. Fuzzy Logic

As it has been already mentioned, the fuzzy logic uses common concepts to regulate system, so the functioning of the algorithm also should be defined with human similar rules and statements. The set of these rules, that defines functioning of the algorithm, is a knowledge base. In order for any fuzzy logic algorithm proper function, it is necessary to accordingly create knowledge base, since it is the cornerstone of the entire algorithm. So the more accurate and comprehensive is this knowledge base, the better functionality of algorithm can be achieved to solve its related problem. This article describes functioning of the algorithm with knowledge base consisting only of two input arguments—temperature of the chamber and heating inertia. Such knowledge base has been created based on basic knowledge of

Table 1 Knowledge base of fuzzy logic algorithm for temperature control of drying chamber.

Temperature	Inertia	Power
Very low	-	
Low	Very low	Full (Very high)
Low	Low	
Medium	Very low	
Low	Medium	High
Low	High	
High	Very low	
Medium	Low	Medium
Medium	Medium	
Low	Very high	
Very high	Very low	
High	Low	
High	Medium	Low
Medium	High	
High	High	
Medium	Very high	
Very high	-	Off (Very low)
High	Very high	

physics and common sense and intuitive feels of authors. This knowledge base is summarized in Table 1.

Also, in order to calculate output power it is required to know the membership functions of the terms, that is define mathematically every logical statement of knowledge base. It is relatively simple to implement, so, for example in Fig. 1, the satisfaction degree to linguistic statement in percentage of the parameter, where 1 in y axis corresponds to “fully met”, and 0 accordingly “not met entirely”. X axis shows percentage of the parameter with 1 corresponding to 100%.

With MATLAB Fuzzy Logic Toolbox [6] it is possible to estimate preliminarily output parameter (in this specific case it is output power) dependency on input parameters (temperature and inertia). The algorithm described in the present article calculates output parameter value with Mamdani algorithm and bisector method of defuzzification of the resulting term [4, 6]. Such decision is based on optimization of the calculation processes, since in such case during defuzzification process it is possible to replace multiplication and summation operations in centroid

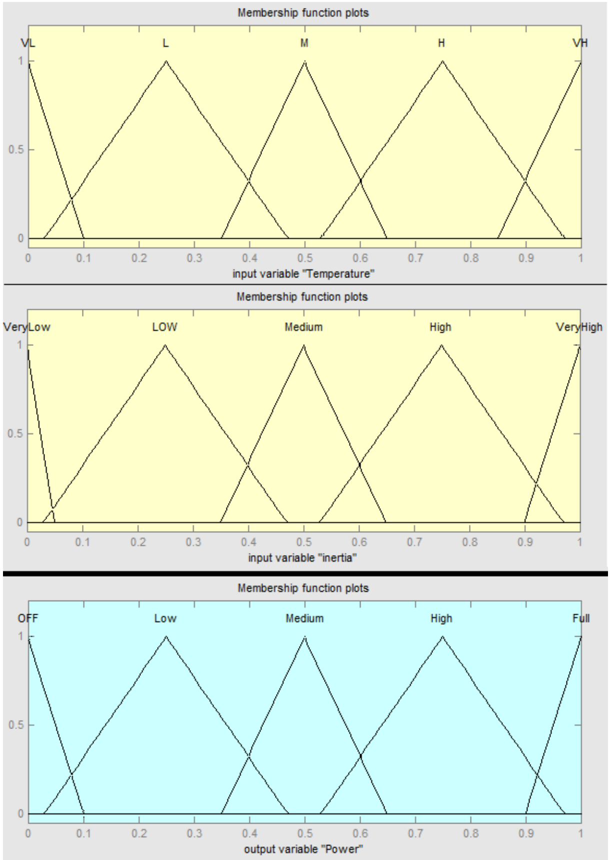

Fig. 1 The plots of membership functions for input and output parameters of fuzzy logic knowledge base.

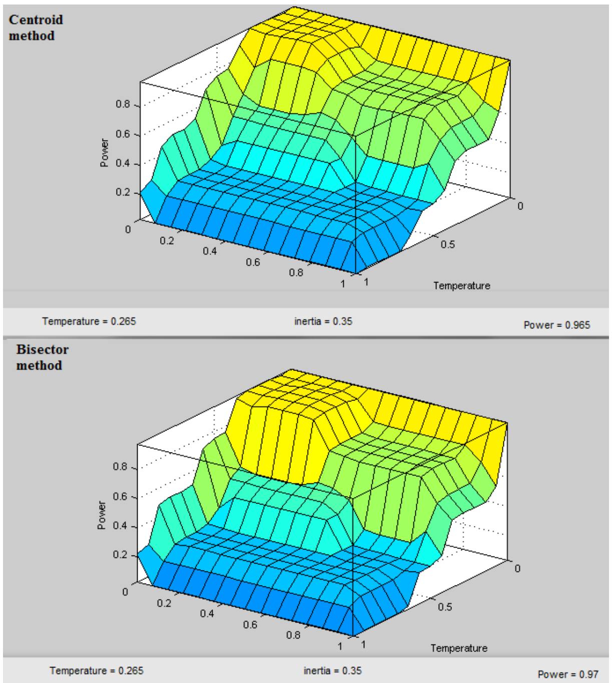

Fig. 2 The surface plots of output power dependence on temperature and inertia for centroid and bisector defuzzification methods.

method with summation operations only in bisector method [7]. These methods, centroid and bisector, are similar, since they require to calculate central point [4, 8]. However, in order to be certain that change of the defuzzification method will not lead to incorrect calculation of output power and it will correspond to knowledge base from Table 1, the simulation in MATLAB has been performed and the resulting surfaces for every method are shown in Fig. 2. (Defuzzification procedure allows to define a mathematical value for any fuzzy logic).

At this stage the developer can check if his knowledge base is created correctly. If the dependence corresponds to expected knowledge base, the development of the algorithm is continued. For temperature (1) and inertia (2) percentage values the following expressions have been used:

$$T = \frac{t, ℃}{MAX\ \ t, ℃} \qquad (1)$$

$$inertia = \frac{(Current\ t, ℃ - Previous\ \ t, ℃)}{MAX\ \ t, ℃} \qquad (2)$$

3. Implementation

In order to implement fuzzy logic algorithm the controlling device has been developed for drying chamber magnetic starter control with relay as a controlling element. The fuzzy logic algorithm is implemented with program logic shown in Figs. 3-4.

Current algorithm was specially designed in accordance with designed device properties, so its work is optimized for the specific device. As it can be noticed from algorithm, designed device uses relay as a control switch for magnetic starter that regulates the output power of the heater. This is the reason why fuzzy logic algorithm is realized as a function from the main program only after fuzzy logic flag is set, that the time intervals between state changes should be long enough to ensure proper relay work without damaging it. So the interrupt timer is referred to fuzzy logic algorithm as well as it helps to control the time of one whole cycle and monitors the relay state according to calculated power output value. The minimal step for output power for current algorithm is 0.1% and it will take a 50 milliseconds time, so the whole cycle will last 50 seconds.

To ensure this algorithm work PIC32MX440F256H microcontroller was chosen. This microcontroller has a

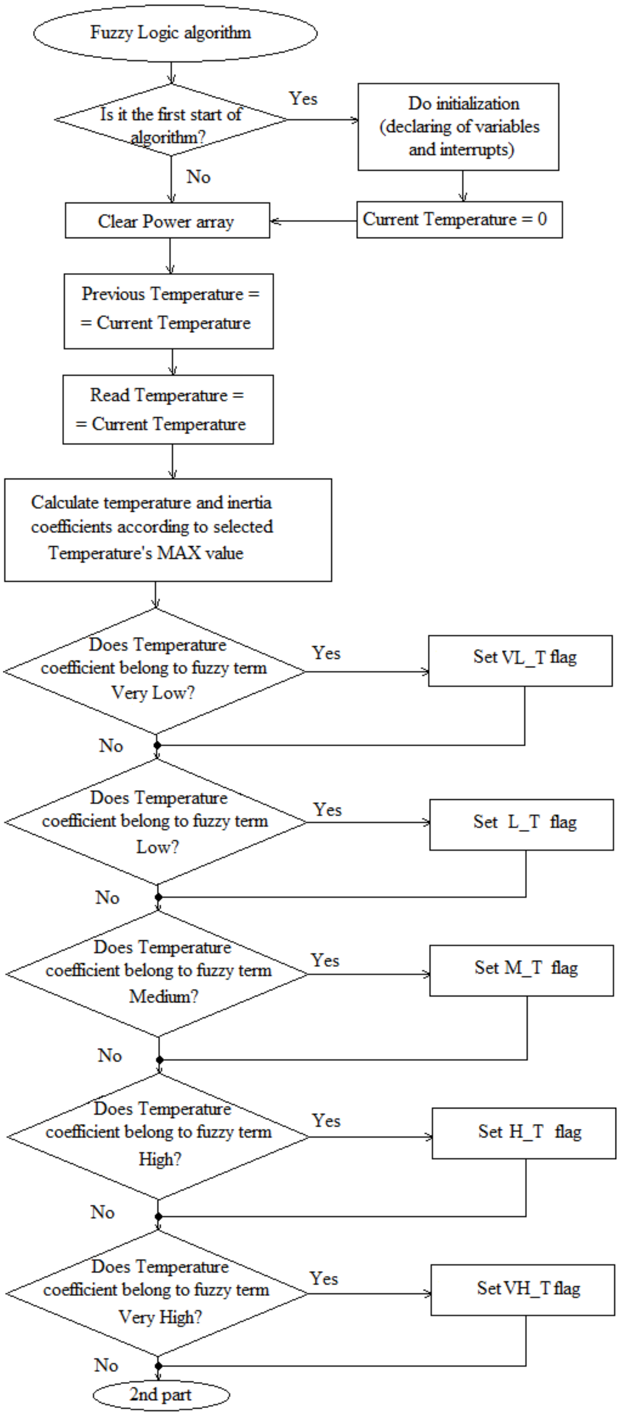

Fig. 3 The first part of the fuzzy logic implementations algorithm.

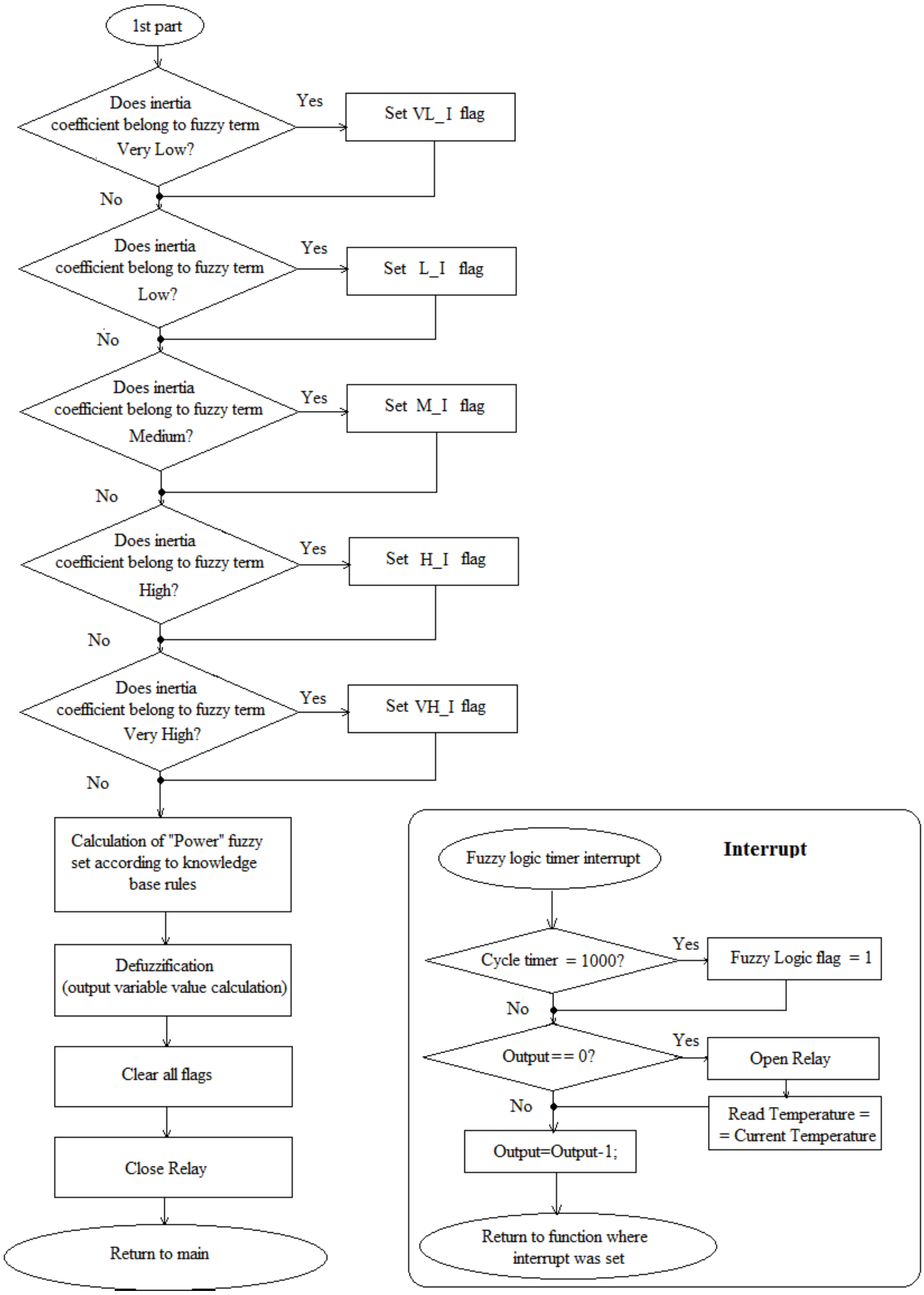

Fig. 4 The second part of the fuzzy logic implementations algorithm.

good tact frequency of 80 MHz and program memory size of 256 KB, that should be enough to ensure work of fuzzy logic algorithm as well as to implement functions of data exchange and to ensure the work of LED display. The other advantage of this microcontroller is USB 2.0 On-The-Go peripheral. Also the choice of MCU was done due to author had a previous experience of the work with the specified model.

4. Experimental Results

When program has been created and debugged, the several tests in different environments have been

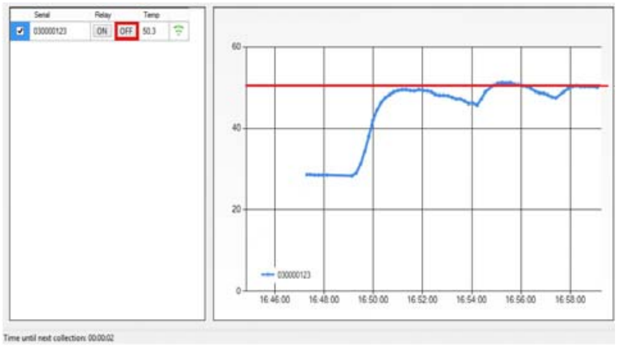

Fig. 5 Temperature measurement results in open room with compact heater.

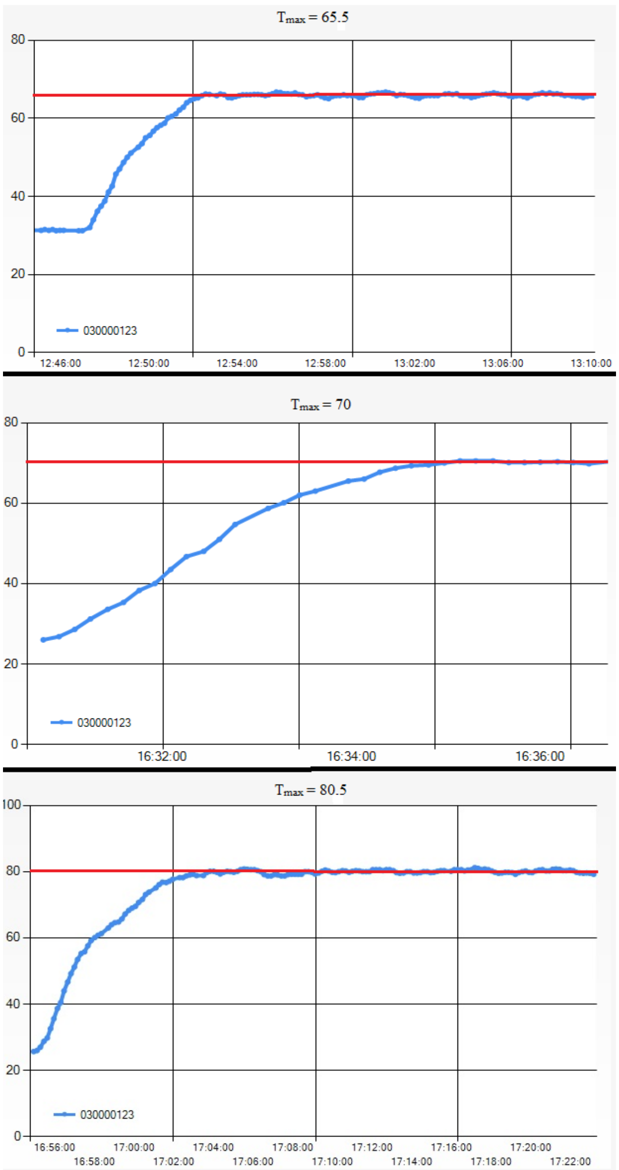

Fig. 6 Temperature measurement results for various ovens with different maximum values of the temperature to be maintained.

conducted to estimate the efficiency of the created algorithm. At the beginning, the test has been conducted in open room, that is the oven or drying chamber hasn't been used yet. Instead the compact heater has been used to heat the temperature sensor. The temperature measurement results are shown in Fig. 5.

As it can be seen from Fig. 5, Plot, the fluctuations of the temperature are noticeable. However, as it has been previously mentioned, taking into account the specifics of the system, this can be considered a good result. In average, the temperature changed in range from 47.8°C to 50.9°C. The preset temperature value to be maintained is shown in red, the measured value is shown in blue. If the test is continued over a longer time interval, the same behavior remains.

It has been observer, that in overall, the temperature is lower than preset value to be maintained, however for even a slight increase of output power the overheat is achieved. This concludes that the board with temperature sensor cools down faster than one cycle of fuzzy logic. However it is not recommended to decrease the time interval of one fuzzy logic cycle due to construction of the device, since relay controls the on/off time and too frequent switching of this relay can lead to its damage. However, when conducting the test in real oven, where cool down process is significantly slower, it is possible to achieve required results, as is shown in Fig. 6.

The Fig. 6 shows the testing results with maximum temperature values set to 65.5°C and 70°C for different ovens. The open-type oven has been used in tests as well and its front door has been always open. In this experiment the maximum temperature has been set to 65.5°C and the oscillations of the temperature reached up to 1.7°C.

6. Conclusions

During the testing the fuzzy logic temperature control algorithm has proven to be safe and capable of correct operation. However the preset temperature value hasn't been maintained precisely and there have been fluctuations. It is necessary to remember that fuzzy logic algorithm efficiency is based on knowledge base, created by human, who has to understand the controlled system or to be an expert in this field. However, the authors of the article created a simple knowledge base with common physics knowledge and their logical understanding of the process, so the result that have been achieved can be considered satisfactory. The algorithm, that has been created, is universal that means it can adapt to change of the system parameters. However, during the tests it has been observed, that this adaptation also has its limits. So, when the heating system begins to cool down faster than one cycle of fuzzy logic, it is impossible to maintain required temperature value very precisely and avoid fluctuations of the temperature entirely.

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