

Application of fuzzy logic methods to modeling of the process of controlling complex technical systems

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Abstract. In recent decades, the concept of “fuzzy” control has emerged in engineering practice, including machinery building, when a complex technical object is controlled in conditions of incomplete and / or insufficiently formalized information. Such systems are often characterized by insufficient reliability and degree of initial data formalization. One of the approaches to such objects is to use fuzzy logic methods. The first step of such processes modeling should include determination of input and output variables and their membership functions and creation of a knowledge base in the form of a set of “IF-THEN” rules. The Mathcad computing system is considered as a tool for modeling processes with fuzzy logic methods using the battery charging control process as an example. This paper presents detailed analysis of advantages and describes software implementation for the Mamdani algorithm. However the proposed approach can be used for other algorithms.

1. Introduction

Fuzzy logic was actually invented by Lotfi Asker Zadeh, a mathematician and computer scientist, and a professor of computer science at the University of California at Berkeley [1]. In set theory, the usual (“crisp”) set A is considered as a part of some universal set U . For example: U is the set of all types of machines; A is the set of machines with software numerical control. In this case, it is possible to say unequivocally about each element of the universal set if it belongs to set A . If we introduce the concept of membership function of an element to a crisp set A , then it will take two values: 1 – if the element belongs to set A , and 0 – otherwise. The main idea [1] was that for some types of objects the membership function can take any values on the interval $[0; 1]$. In this case, the value of the membership function characterizes the probability that an element belongs to the set A . Later on, L. Zadeh and his followers introduced the concepts of operations on fuzzy sets, fuzzy inference and the concept of a linguistic variable, which values are fuzzy sets. A similar approach is used both for modeling complex technical objects and for creation of real automatic control devices for such objects [2-4].

This paper discusses the application of fuzzy logic methods to the simulation of a battery charging control system in the Mathcad application package.

2. Principles of creating a model based on fuzzy logic

As it was noted above, the concept of fuzzy logic is based on the concepts of fuzzy sets, fuzzy statements, etc. Fuzzy logic methods refer to the so-called “soft” computing based on a probabilistic approach.

Zadeh, using Fuzzy logic, introduced the concept of fuzzy function and developed the principles of constructing fuzzy regression models. Within this approach, the concept of a fuzzy linguistic variable was introduced; its values can be expressed in terms of the types “low”, “moderate”, “large”, “very high”, etc. The collection of linguistic values of a fuzzy variable forms the so-called term-set.

For example, temperature is often an important parameter of technological processes, including mechanical engineering [5-8]. The fuzzy variable “Temperature” may have a term-set of values {“Very low”, “Low”, “Mid”, “High”, “Very high”}.

The main types of membership functions are triangular, trapezoidal, piecewise linear, the Gaussian, sigmoid, and other functions. An example of a trapezoidal membership function is shown in Figure 1. Four parameters $[a \ b \ c \ d]$, defining x – coordinates of selected points are required to define a trapezoidal membership function. In Figure 1 the parameters are $a = 0$, $b = 10$, $c = 15$, $d = 25$.

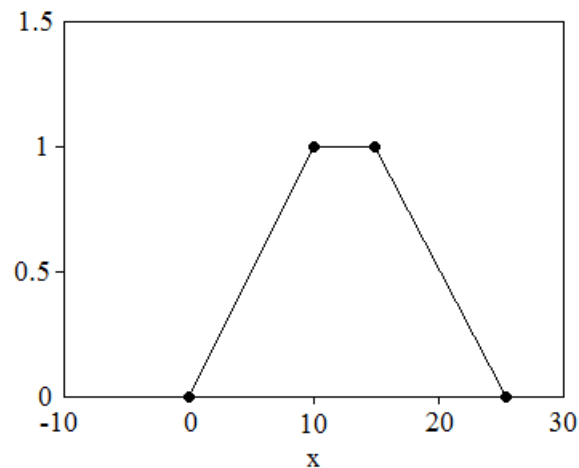


Figure 1. Parameters of trapezoidal membership functions.

We should note that the triangular membership function can be considered as a special case of a trapezoidal function, where the variable b coincides with the parameter b .

Speaking of fuzzy logic, most often we mean the fuzzy inferencing systems, which underlie various expert and control systems. It is comprised of four steps that transfer the system inputs to the appropriate system outputs. These steps are:

1. Fuzzification, which involves determination of input parameters when crisp inputs having their own group of membership functions are specified.
2. Rule Evaluation, which may be understood as partial imprecise knowledge on some crisp function, so-called fuzzy IF-THEN rules.
3. Aggregation (composition). At this stage, the “truncated” membership functions of the variable output are built, which are then composed together to form one fuzzy set.

The construction of the truncated membership function of the output variable is shown in Figure 2. The membership function of the input variable is trapezoidal, and the output variable is triangular. The crisp value of the input variable is approximately 1.5.

A similar procedure is carried out for each input variable. Then a final fuzzy set is constructed for the output variable. In the Mamdani algorithm, the combination of truncated membership functions of a variable output is performed using the MAXIMUM operation if the corresponding rule matches the logical OR, and using the MINIMUM operation if the corresponding rule is closely related to the logical AND [9,10].

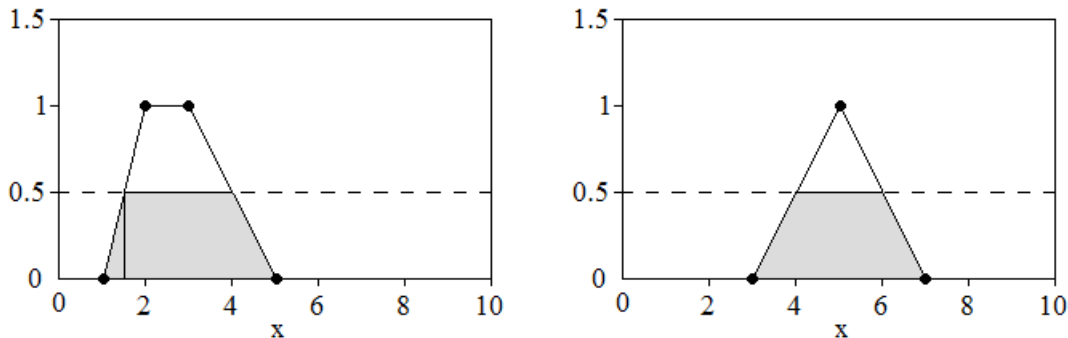


Figure 2. Construction of truncated membership functions.

4. Defuzzification, which involves the process of transposing the fuzzy outputs to crisp outputs. At this stage, a crisp value of the output variable is obtained. If the centroid method is used, the corresponding value is equal to the x-coordinate of the center of gravity of the figure obtained in Step 3.

Currently, Fuzzy Logic subsystems are integrated in the software of many modern computational mathematics systems, such as Mathematica and Matlab. The Matlab fuzzy toolbox is one of the most convenient software solutions in this field.

The main benefit of this approach is visual modeling, when quite complex programs can be created without writing software code that is generated automatically. Another advantage of Matlab is that it allows one to create a computer model using visual simulation methods, for example, in the subroutine Simulink, generate automatically the readable C code, and after transferring the code into the microcontroller, obtain a device that controls a real technical object, without writing a program code.

However, the use of Matlab has several disadvantages. In particular, this software product is quite expensive, and when creating programs you can use only the Mamdani algorithm or the Sugeno algorithm. The use of other algorithms requires increasingly complex development methods for which Matlab is not the best choice.

This paper shows the implementation of the Mamdani algorithm in the Mathcad application package. Based on this approach, any other computational algorithm can be implemented.

3. Fuzzy logic battery charge model

Let us consider a simplified model of battery charging control based on the following assumptions [11]:

- the device has two operation modes: charge-sustaining and fast-charging modes;
- in the charge-sustaining mode, a low amount of current flows into the battery;
- in the fast- charging mode, all available current moves to the charger;
- if the battery is fully charged, the incoming current causes its heating-up, so if the temperature is “high”, it is necessary to switch from the fast-charging mode to the charge-sustaining mode;
- if the battery voltage has become “high”, the device should automatically switch to the charge-sustaining mode;
- if the battery temperature is “low” and the voltage is also “low”, the device should activate the fast-charging mode.

The last three rules form the knowledge base of the device control system.

To control the charging process, we introduce two fuzzy variables: “Voltage” and “Temperature”. The fuzzy variable "Temperature" is described by the term-set {"Cool", "Warm", "Hot"}. To describe this variable, trapezoidal membership functions were used with the parameters [0 0 15 25] (Cool), [15 25 35 45] (Warm), [35 45 90 90] (Hot).

The fuzzy variable “Voltage” is described by the term-set {"Low", "Mid", "High"}. Trapezoidal

membership functions with parameters [0 0 5 10] (Low), [5 10 20 25] (Mid), [20 25 50 50] (High) were also used to describe this variable. The graph of the membership function for the variable "Voltage" is shown in Figure 3.

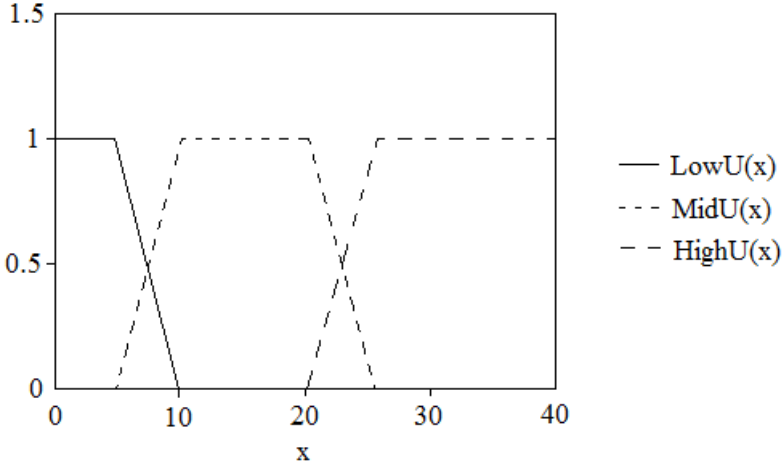


Figure 3. Membership functions of the variable “Voltage”.

The output variable (ChargeMode) is a value in the interval [0; 1], which term-set {Fast (fast-charging mode), Trickle (charge-sustaining mode)} is characterized by two trapezoidal membership functions with the parameters [0 0 0.4 0.6] and [0.4 0.6 1 1], respectively. The developers must define the boundary value of the output variable, which determines the transition from one mode to another.

For example, we can assume that one should switch to the charge-sustaining mode if the value of the output variable exceeds 0.5.

The implementation of the Mamdani algorithm in Mathcad is described in detail in [12].

An example of calculations is shown in Figure 4.

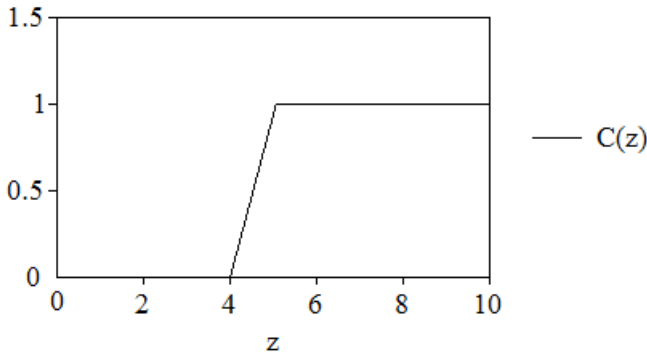


Figure 4. The example of calculations using the Mamdani algorithm.

The Mamdani algorithm is chosen as the fuzzy logic algorithm. The crisp value of the output variable is 0.744. In this case the voltage and temperature are quite high so that the switch to charge-sustaining mode can happen automatically. Comparison of the results with those obtained using Matlab shows their identity.

4. Conclusion

The results of our study showed that fuzzy logic algorithms could be successfully implemented in the Mathcad application package. In particular, in this paper, a battery charging system controlled by a

fuzzy logic algorithm was presented. We carried out a comparative analysis of calculations which seemed identical.

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