Possibility of using Matlab application to propose fuzzy computer model

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Abstract. More and more organizations in various fields apply the principles of the Industry 4.0 philosophy. The result, among other benefits, is the acquisition of a large amount of data. Data can be of great importance to them in terms of decision support, analysis and, last but not least, as a resource for simulations and computer models. Currently, various approaches and software applications can be used to create models. One of the applications that allows the creation of computer models in various fields is Matlab. Diversity of use is ensured by different sets of tools, which are specifically focused on individual areas and thus provide the necessary tools. In the presented paper we focus on the possibilities of using fuzzy approach in the design of a computer model in the field of heating with the tools of the Fuzzy Logic Controller toolbox. The basis for creating the model will be historical data obtained from the real object. The individual tools of the toolbox, the creation and presentation of rules will be described, as well as the connection of the proposed model with the Simulink environment.

1. Introduction

The use of advanced techniques in the modelling of real systems currently has a firm place in almost every area. The increasing quality of model design is ensured using advanced software tools in conjunction with artificial intelligence techniques. This area also includes the application of fuzzy logic in the design of dynamic systems models. The founder of fuzzy set theory and fuzzy logic was Professor Zadeh, when he published an article by Fuzzy Sets in the journal Information and Control in 1965 [1]. In the eighties of the twentieth century, algebraic development of fuzzy logic took place in various aspects. Various generalizations of classical logic and extensions of fuzzy logic have been studied. Since its inception, a number of models have been created to describe various systems through the application of fuzzy logic. Applications based on fuzzy logic range from control unit design [2], quality assessment [3], industrial systems, biomedicine, technology [4], decision analysis technology and recognition. The development of hardware and software tools has enabled further possibilities of applying fuzzy access through developed software programs that are able to bring suitable tools for a wider range of users. One of such tools is the Matlab software and its toolbox - the Fuzzy Control Designer.

The possibilities of this toolbox will be presented on real data from the process of heating buildings. Data were measured and recorded by sensors and made available through the user interface of the SCADA system (Supervisory Control and Data Acquisition), which allows data export at selected time intervals. The SCADA system is a type of industrial control system for remote monitoring and control that works with coded signals via communication channels. It provides data sets of monitored...
parameters but does not include higher level of evaluation [5]. The following figure shows the user interface of the system.

![User interface of SCADA.](image)

**Figure 1.** User interface of SCADA.

We obtain data divided into 30 columns and 4699 rows which represent one whole year using export possibility from user interface. Each column represents one examined parameter. When designing the model, we assume that the data have already been pre-processed, i.e. any duplicate values have been removed. In terms of model design and use of Matlab tools, we can use the following variables:

- outside temperature,
- date and time,
- gas consumption,
- required/actual water temperature in individual circuits, etc.

2. Brief description of used method and tool

In the next section will briefly describe the procedures and tools that formed the basis of model design.

2.1. Fuzzy logic introduction

Models created using fuzzy logic based on fuzzy set theory are used to express the experience and knowledge of the human operator in terms of language variables. These transferred experiences are called fuzzy rules [2]. Fuzzy systems are able to approximate any real function on a compact fuzzy subset. The main advantage of fuzzy logic compared to conventional approaches is that no mathematical model is required and all available process information can be used to design a fuzzy model [6]. An important part of the fuzzy approach is using linguistic expressions, which represent linguistic values in fuzzy statements. With these statements, it is possible to describe knowledge about the real world, which was gained either from one's own experience or from the experience of others. Each statement can be assigned its truth value. In this context, it is necessary to define a linguistic (linguistic) variable as a variable whose values are expressions of natural or formal language. Such simple (atomic) fuzzy statements can then be combined into one compound fuzzy statement using the logical conjunctions AND and OR.

There are usually three types of fuzzy system: Mamdani, Sugeno and Tsukamoto. The following processes can be specified for all these types [7]:

- Fuzzification - represents the first process in which the values of the selected membership function are assigned to the input variables according to chosen fuzzy sets. Both input and output are fuzzified into fuzzy linguistic terms with the fuzzy membership function [8].
- Creating rules - the number of rules is designed to represent the base of knowledge.
Defuzzification - based on the selection of the fuzzy system type, an output value is determined respecting the set rules.

In the Figure 2 are shown the parts of fuzzy logic system.

![Figure 2. Parts of fuzzy logic system [9].](image)

In the presented paper, the Mandami system, which is the most used in the design of models, will be applied [7].

The selection of the appropriate membership function plays an important role in the design model. Assigning a membership function can be considered a technique for solving empirical problems based on experience rather than knowledge. Fuzzy logic contains several built-in types of membership functions, which are generally shown in graphical form. The simplest membership functions are created using a straight line. The membership function is essentially a curve that defines how each point in the input space is mapped to an accessory value. The membership function that represents a fuzzy set is usually denoted by \( \mu(A) \). For the element \( x \) of \( X \), the value of \( \mu_A(x) \) is called the degree of membership \( x \) in the fuzzy set. The degree of belonging \( \mu_A(x) \) quantifies the degree of belonging of the element \( x \) to the fuzzy set [10]. The choice of the type of membership function needs to be considered in the design, as the use of an inappropriate membership function can lead to large variations in the evaluation results [11].

2.2. Matlab

Matlab contains about 300 problem-oriented application libraries for various areas of application, called Toolboxes. One of them is Fuzzy Logic Designer, which is a graphical superstructure focused on solving fuzzy logic tasks (Fig.3). The library allows us to create and edit fuzzy inference systems using graphical tools or from the command line to call functions. The task solved with Fuzzy Logic Designer can be integrated into process models created in Simulink. The library has implemented fuzzy systems Mandani and Sugeno.
Fuzzy Logic Designer Toolbox is a set of MATLAB tools using fuzzy logic that provides analysis, design and simulation of functions systems, applications and the Simulink block [13]. Through this toolbox it is possible to:

- Design Mamdani and Sugeno fuzzy inference systems.
- Add or remove input and output variables.
- Specify input and output membership functions.
- Define fuzzy if-then rules.
- Select fuzzy inference functions for:
  - And operations
  - Or operations
  - Implication
  - Aggregation
  - Defuzzification
- Adjust input values and view associated fuzzy inference diagrams.
- View output surface maps for fuzzy inference systems.
- Export fuzzy inference systems to the MATLAB® workspace.

3. Model design

3.1. Input parameters preparation
As a first step, it is necessary to specify the individual input parameters that affect the output value – average gas consumption. In the presented paper it will be the average outdoor temperature - temperature and year part - season:

- Winter – January, February, December
- Spring – March, April, May
- Summer – June, July, August
- Autumn – September, October, November

We divide the outdoor temperature into individual temperature intervals. The values obtained are shown in the following table.
Table 1. Input data.

| Linguistic interpretation | Winter | Spring | Summer | Autumn |
|---------------------------|--------|--------|--------|--------|
| VL (Very Low)             | 515.18 | 595.96 | 54.08  | 397.41 |
| L (Low)                   | 449.49 | 440.71 | 30.68  | 282.35 |
| M (Medium)                | 272.81 | 223.34 | 82.56  | 135.87 |
| H (High)                  |        | 31.32  | 23.15  | 26.69  |
| VH (Very High)            |        |        |        |        |

The triangular form of the membership function was used \((\text{trimpf})\) for the individual input parameters. The shape of this function is shown in the Figure 4 [14].

The following division with the appropriate word designation is proposed for the monitored output parameter – average gas consumption (Table 2).

Table 2. Output data.

| Linguistic interpretation | Consumption [m³] |
|---------------------------|------------------|
| VH (Very High)            | > 500            |
| H (High)                  | 350 - 500        |
| M (Medium)                | 150 - 350        |
| L (Low)                   | 40 - 150         |
| VL (Very Low)             | < 40             |

3.2. Fuzzy Control Designer

Based on the design, we gradually enter the individual parameters into the Fuzzy Control Designer environment. As a first step, it is necessary to mark the individual inputs and assign them the proposed membership functions. If there are more than predefined number of functions, the required number of additional functions can be added. The following figure shows the proposed computer model (Fig. 5) and used membership function (Fig. 6).
In the case of determining the season for winter, two variables were set with respect to the designation of the $x$-axis, which represents the designation of the individual months. The specific designation $W$ represents January and February and the designation $W1$ indicates the month of December.

After determining the membership functions for the input variables and for the output variable, we will create individual rules. Example of a few rules:

IF ($\text{temperature is VL}$) and ($\text{season is } W$) then $\text{consumption is VH}$

IF ($\text{temperature is L}$) and ($\text{season is } Au$) then $\text{consumption is H}$

IF ($\text{temperature is M}$) and ($\text{season is } Sp$) then $\text{consumption is M}$

IF ($\text{temperature is H}$) and ($\text{season is } Su$) then $\text{consumption is VL}$

IF ($\text{temperature is VH}$) and ($\text{season is } Au$) then $\text{consumption is VL}$
The Figure 7 shows the graphical rule interpretation in Rule Viewer environment.

![Figure 7. Graphical interpretation of rules.](image)

3.3. Simulink

Simulink is an essential toolbox for the simulation of linear and nonlinear dynamical systems. It enables system modelling using graphical flow charts [15]. The basis of this toolbox are its libraries, which allow us to create models of dynamic systems. When we use for model design the fuzzy approach, it has a library (Fig. 8) that is designed for this purpose.

![Figure 8. Fuzzy Logic Toolbox.](image)

The individual variables will enter the given block according to the order of the proposed computer model. Furthermore, blocks from libraries will be used for input and output. The result is a value representing an estimate of average natural gas consumption. The implementation designed model represents Figure 9.
4. Conclusion

The presented paper describes a powerful software tool that allows us to design computer models of dynamic systems using fuzzy sets. Fuzzy’s approach to system model design mimics human expression, which includes certain inaccuracies. The knowledge base consists of expert knowledge interpreted in the form of IF-THEN rules. Using them, it is easier to model systems that are very complex, indeterminate or imperfectly mathematically described. Another great advantage is that no mathematical or physical specification of the model is required. In the paper on the presentation of the possibility of using the tools of the Matlab software system, real data were used, which were obtained through sensors and the SCADA software interface. In the following examination of this computer model, we will focus on the analysis of other possible influences that we assume may affect the results obtained from the model. The current analysis of the measured data shows that large weather fluctuations can play an important role in determining the average natural gas consumption. For this reason, we will deal with the possibility of extending the current model with additional input, such as a count of days with extreme outdoor temperature outside standard limits. By extending the model and deeper analysis of the obtained data, it is possible to increase the quality of the model and thus obtain a more accurate output value.

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