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Speed regulation in fan rotation using fuzzy inference system

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ABSTRACT

Fuzzy logic, being one of the methods of artificial intelligence, converts human way of thinking into an algorithm, using certain mathematical methods. Logic based on a fuzzy set is polyvalent, each statement is associated with a degree of authenticity – the value of membership function. Fuzzy logic is used in cases in which knowledge is mostly experiential and expressed through words. This work presents the application of fuzzy logic in fan speed regulation. The main goal of this work was establishing an expert system that would incorporate the aforementioned method of artificial intelligence into inference mechanism. The advantages of fuzzy logic are: wide use and flexibility, tolerance to data imprecision, applicability in classic control problems and its linguistic variables based approach.
The assumption is the following: collecting of a large number of input and output data sets of greater quality which are necessary for deduction mechanism of fuzzy logic, will enlarge the possibilities of further researches and application of fuzzy logic.

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1. Introduction

Knowledge of a certain problem that is to be analyzed can be divided in two fields. One is objective knowledge, commonly presented with “linguistic information”. The other is subjective knowledge. Examples of objective knowledge are basic differential equations in mechanics. Subjective knowledge is expressed in linguistic terms such as “close”, “slow”, “strong”, “small”.

Fuzzy logic is used in situations when it is difficult to express the knowledge of a system through mathematical models, or when knowledge is mostly experience-based, or expressed in words and in *if-then* rules. Fuzzy logic becomes suitable for approximative analysis based on incomplete and imprecise data, as shown in examples 1 and 2. *Example 1*: Temperature measurement in a room If there are several people in a room at the same time,and they are asked to estimate the temperature in the room, we will get a whole range of answers like “cold”, “hot”, “a little cold”, “cool”, “a bit too hot” etc. Each of these answers will depend on the testees’ own senses and the answers will be subjective. If there is a thermostat in the room, with very clear “view” on whether it is “cold” in the room (the heat system is ON), or “hot” (the heat system is OFF). The difference between human approach and binary approach with the use of thermostat is very clear here. *Example 2:* “I will be back in few minutes!”

The statement without firm boundaries as this one shows a fuzzy character. In these examples, and in many others, answers **yes** or **no**, are not always possible.

2. Fuzzy logic

In 1965 Lofti Zadeh introduced the concept of *fuzzy sets* [1], which allow more degrees in a set. Degree of set membership is marked with numbers between 0 and 1, i.e. with a number from the interval [0, 1]. Due to the fact that the interval [0, 1] contains endless sequence of numbers, endless succession of the membership degrees are, therefore, possible. In fuzzy sets logic, an element can have a certain degree of membership to a set (or to more sets). As classical logic is based on classical sets theory, fuzzy logic is based on fuzzy sets theory.

Fuzzy logic is based on the theory of fuzzy sets which can be interpreted as generalization of the theory of classical sets. The starting point for fuzzy sets is generalization of a two-members set. By extending of the two-members set {0, 1} we change the nature of characteristic function which is called the cognition function, and marked as $\mu_A(x)$.

If X is a universal set, and A is an arbitrary set, according to classical Boole logic, both membership and non-membership of an arbitrary element x from universal set X to set A are determined by *characteristic function* $\chi : X \to \{0,1\}$ defined as:

$$\chi(x) = \begin{cases} 1, x \in A \\ 0, x \notin A \end{cases}$$

In fuzzy logic characteristic function $\chi(x)$ is substituted with membership function $\mu(x) : X \to [0,1]$.

If an element $x \in X$ *certainly* belongs to set A then $\mu(x) = 1$ and if it *certainly* does not belong to set A, then $\mu(X) = 0$. If the value $\mu(x)$ is a value from the interval [0,1] and if the value is different from 0 and 1, that number is interpreted as the *degree* of membership of the element to the set A**.** When the value approaches to 1, the possibility of membership to the set A increases. If the value approaches to 0, possibility of membership to set A reduces. Fuzzy set A is very often registered as a pair (A, $\mu(x)$). Membership functions are defined according to statistical data and based on the criteria specific for the usage [2] .

2. Fuzzy algorithm

One of the possible algorithms of fuzzy logic is Mamdani model which enables the estimation of a certain characteristic stored within the model[3]. Mamdani model is one of the main algorithms of fuzzy theory. Being the model for characteristics estimation, it is used when the available number of input data sets is "*relatively small"* Sugeno model is another example of a fuzzy logic algorithm. That algorithm is applicable in cases with *"sufficient"* number of input data sets.The mechanism of fuzzy inference system – FIS, can be described in four phases: fuzzification, inference, aggregation, defuzzification.

In the first phase (fuzzification), input variables are fuzzificated. A number of *fuzzy sets* is selected and their *membership functions* are defined for each input variable, based on the total of all information available.

In the second phase (inference), output variables are fuzzificated in analog way, as was done for the input variables in the first phase. In this phase, *fuzzy rules* are selected. Their number and shape depend on the quality of the information available. This is the key phase of the method.

In applying of these rules, crisp values of all input variables are assigned with as many values of membership functions of each output variable, as there are the rules defined.

In the third phase (aggregation) for each variable, the values of membership functions obtained in the previous phase are united. Therefore, the output variable gets one fuzzy set with the defined membership functions. In the fourth phase (defuzzification), a fuzzy value of each output variable is obtained.

3. Use of fuzzy inference system: regulation of speed in fan rotation

Both input and output variables are defined; input – air temperature and output – speed rotation. Table 1 shows the measured data according to which the influence of air temperature to fan speed will be shown through fuzzy logic.

Table 1 Measured data [4]

Air temperature		Fan speed	
4	ice cold	0–30	very slow
0–18	cold	10–50	slow
12–24	room temperature	40–60	middle
18–38	warm	50–90	fast
34	hot	80–100	very fast

4.1. Fuzzifiction

Figure 1 shows standard patterns of input – output membership functions.

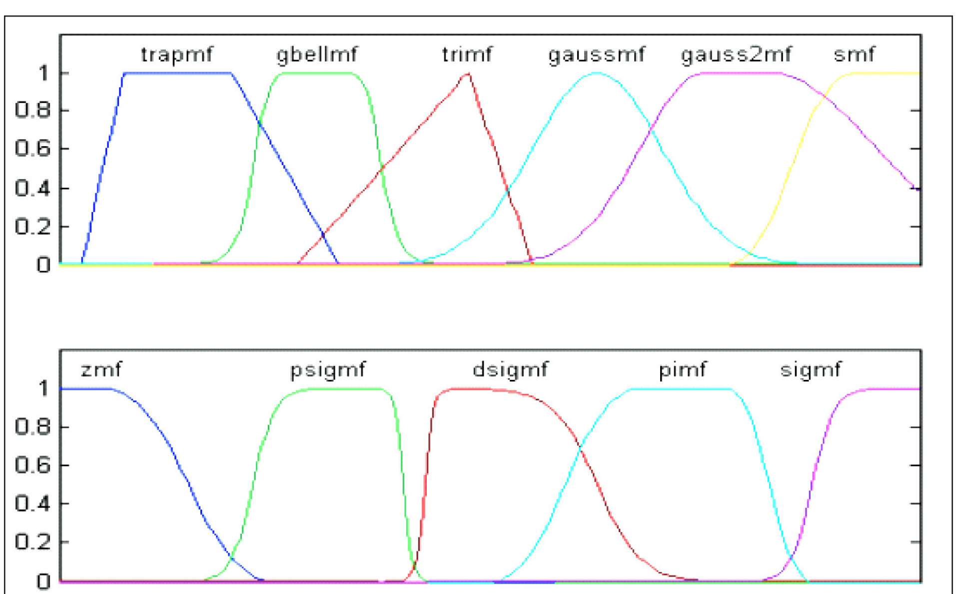

Figure 1 Standard shapes of membership functions [5]

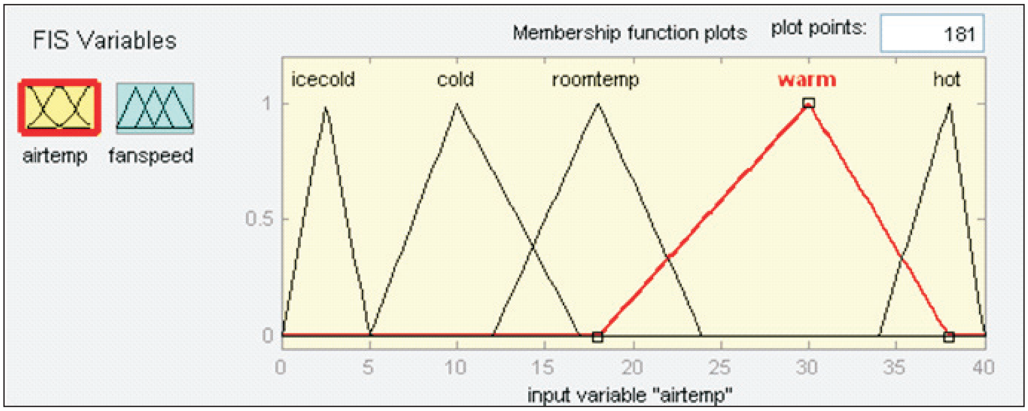

Figure 2 The shape of membership functions for input variable for air temperature [6]

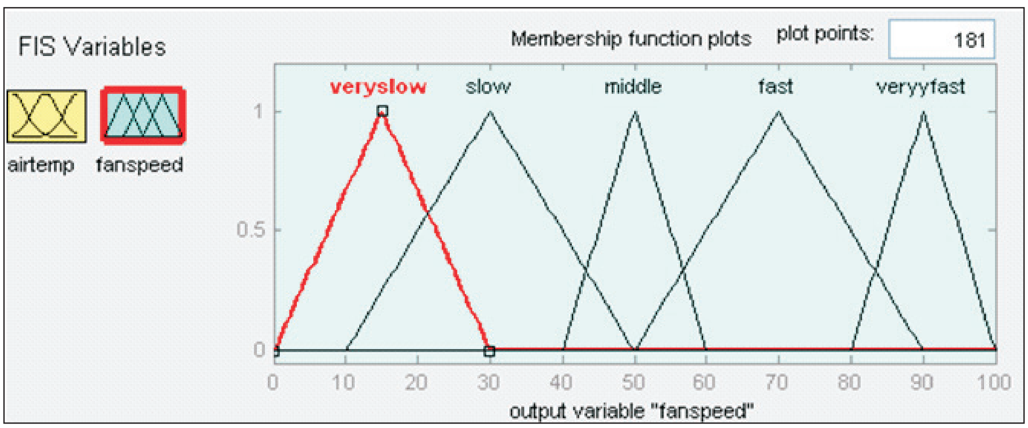

Figure 3 Membership function shape for output variable fan speed (overlapping of fuzzy sets within a universal set) [6]

In this paper, five fuzzy sets were defined for input variable – temperature (ice-cold, cold, room temperature, warm, hot). For output variable – fan speed, five fuzzy sets are defined as well (very slow, slow, middle, fast, very fast). Fuzzy sets for membership functions can overlap within a *universal set,* as is shown in Figure 2.

Functions in the trim shape were chosen for membership functions of all fuzzy sets. Typical value of fuzzy sets associated to the variables are assigned the membership function μ = 1. Triangular membership function is defined by parameters [*a b c*], where *a* stands for the left intersection of membership function μ = 0*, b* is the middle vertex of typical value with membership μ = 1*,* and *c* is the right function intersection with membership μ = 0. Figure 2 shows membership functions of fuzzy sets (ice-cold, cold, room temperature, warm, hot) associated with input variable.

After literature data analysis is complete, membership function domain and shape for output variable were established for each membership function (Figure 3).

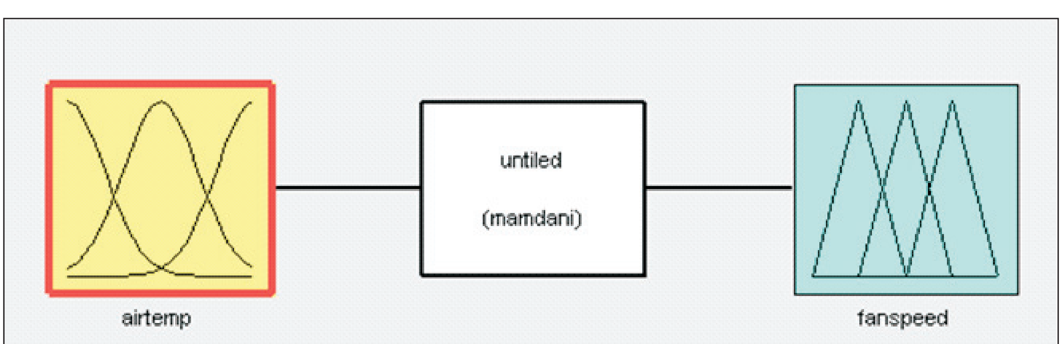

Figure 4 Structure of fuzzy inference mechanism) [6]

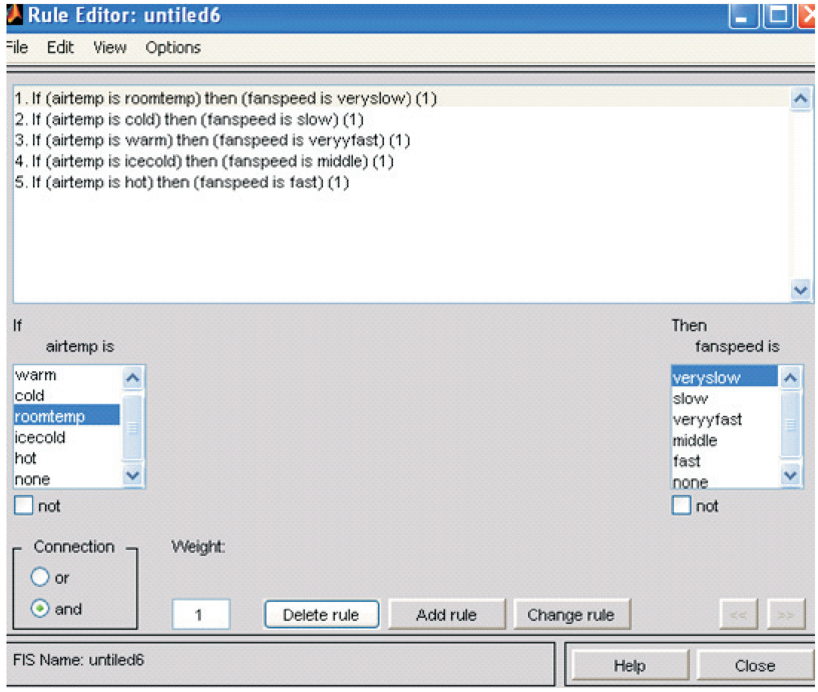

Figure 5 FIS rules

4.2. Inference

Figure 4 shows the structure of fuzzy inference for input variable – air temperature and for output variable – fan speed.

4.3. Aggregation

FIS rules were defined for valuation of output parameter value, which is shown Figure 5. Mamdani model was used to calculate fan speed. Mamdani model is one of the main algorithms of fuzzy theory. As a model for characteristics evaluation it is used when there are *"relatively small"* number of input data sets available. For each fuzzy set, a value which best reflects the linguistic meaning of a set is established.

4.4. Defuzzification

Defuzzification is a process of converting the linguistic results from the base to numeric values. One of the main characteristics of defuzzification is *continuity.* Method of defuzzification is continuous if infinitesimal change of the output variable does not cause sudden change of any output variable why the method Center of area was chosen. The most important defuzzification methods are shown in Table 2. *CoM and CoA/CoG* methods are continuous because of the logic of *the best compromise*, whichs does not show any "leaps" in figures *MoM* method, on the other hand, is discontinuous. In practice, the difference between these methods of defuzzification lies within the method of use either of the logic of *the best compromise* or *the most probable solution* [7].

Method Center of area is applied in this work. In this method, certain fuzzy sets "cut" output linguistic variables, for the amount obtained from implication. Areas under membership coefficient for each linguistic set are superimposed in new fuzzy set (shaded area) and center of gravity is calculated. Calculations of numeric values of linguistic output variables are shown in Figures 6, 7 and 8. They show diagrams of model inference [3].

Table 2 Comparison of various defuzzification methods

	Maximum Center (CoM)	**Maximum Average (MoM)**	**Area Center (CoA, CoG)**
Linguistic characteristics	"The best compromise"	"The most probable solution"	"The best compromise"
Intuition overlapping	Good	Good	Poor, with the use of various MBF shapes
Continuity	Yes	No	Yes
Calculation efficacy	High	High	Low
Application	Control, Data analysis	Recognition of samples, Data analysis	Control, Data analysis

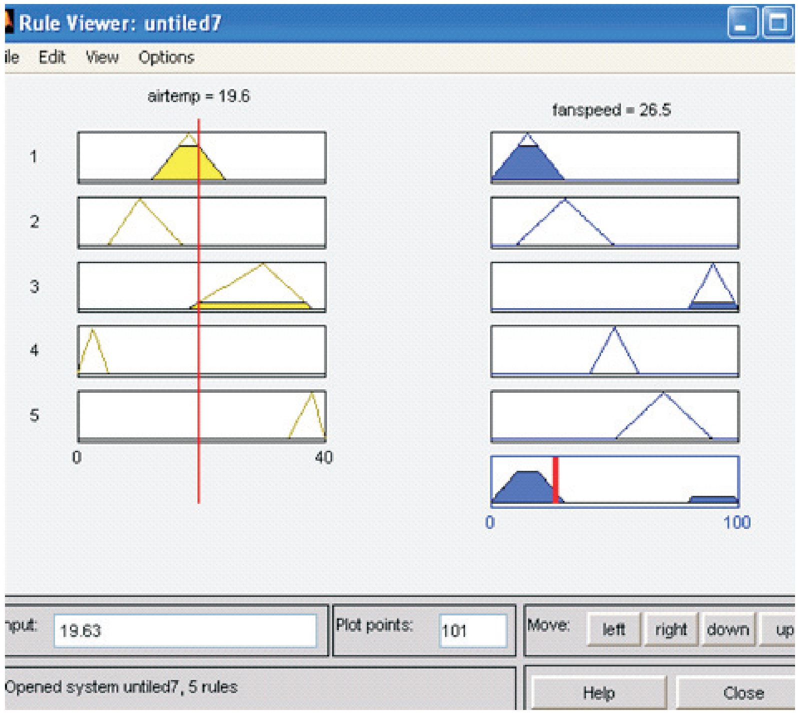

Figure 6 Inference Diagram [8]

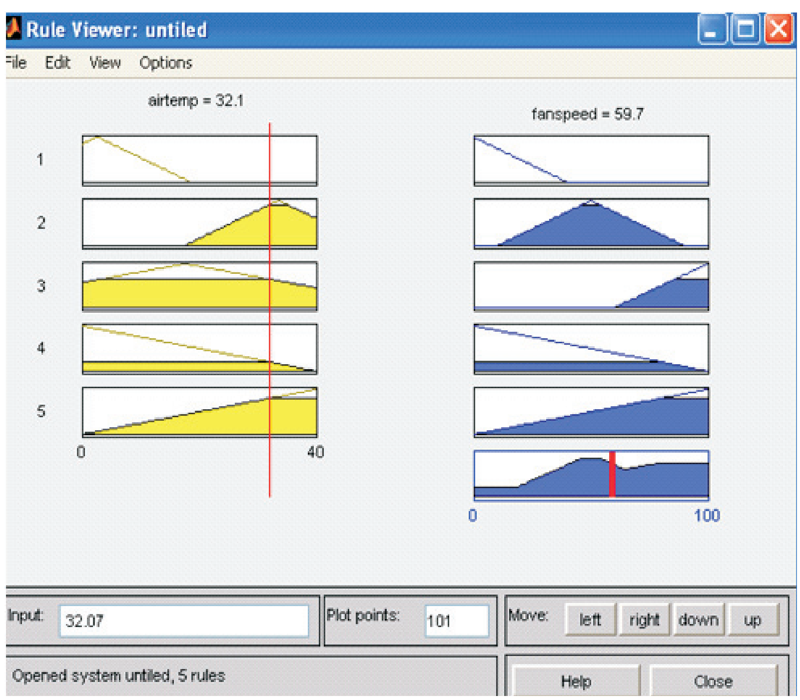

Figure 7 Inference Diagram [8]

According to inference diagram, Figure 6, it is visible that air room temperature matches the average fan speed.

Inference diagram, Figure 7, shows that if the air temperature is higher than 35°, it will match the interval of the highest fan speed.

Figure 8 shows the response function of fan speed estimation for input parameter "temperature", In the case of at least two input or output variables we obtain 3D response functions.

5. Conclusion

In this paper, fuzzy logic was used to analyze the problem of the regulation of fan rotation speed, depending on air temperature. Rules within fuzzy inference mechanism are established in order to register the changes of the parameters, through the help of program tool Matlab, which enables the graphical display of dependance of the parameters observed. From the graphical display of air tempera-

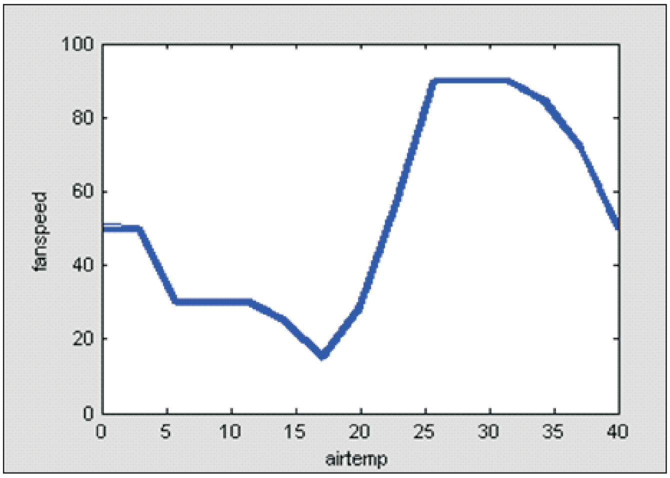

Figure 8 Influence of air temperature to the fan speed [8]

ture influence to fan speed, it can be concluded that room temperature matches average value of fan speed, and that temperatures above 35° meets the highest fan rotation speed. Through inference diagram (Fig. 6, Fig. 7, Fig. 8), also in program package Matlab, it is shown that changes in input parameters influence the value of output parameter, which complies with the measured data, table 1. Fuzzy logic is suitable for situations in which it is difficult to present human sense or answers through classical systems of analogue and digital regulations, such as management systems (navigational equipment in liners) and systems based on human knowledge.

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