Dvelopment of a management systems model of automatic control by using fuzzy logic

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Abstract. Performing control in complex technical systems frequently becomes complex task, especially at the absence of a deterministic model of the system functioning or in conditions of incomplete system information. Often control efficiency under these conditions is not satisfactory. The paper describes control quality improvement approach based on using of fuzzy logic mechanisms on the example of fyzzy-system for controlling diesel engine fuel feed.

Key words: fuzzy logic, fuzzy controllers, diesel engine control, fuel feed control.

STATEMENT OF THE PROBLEM

Management of complex systems is fundamentally different from the optimal (software) control, i.e. the transfer of the system to the desired state in some optimal way. This is because the behavior of complex systems is difficult to predict that is why it is almost impossible to identify and the more "impose" the "best" way of transition to the desired state [1, 3].

The management of complex systems is often carried out under conditions of uncertainty (lack of complete information necessary for the correct control action, lack of adequate mathematical models of operation, several alternatives, etc.).

The uncertainty of the system leads to increased risk due to poor management, which can bring fruit in negative economic, technical and social consequences.

Tools, that allow to provide an efficient system control under conditions of uncertainty, are methods built on the principles of an artificial intelligence using fuzzy logic rules [4,5]. They are based on fuzzy sets and use linguistic notions and expressions for the process control based on fuzzy, incomplete or subjective data, without the need for formalization as it goes in classical mathematical systems.

It is experimentally shown that fuzzy control gives better results compared with those obtained by conventional control algorithms. Fuzzy logic mainly provides effective means of uncertainties and inaccuracies of the real world depiction. With the help of fuzzy logic we solve the problems of harmonization of conflicting criteria of decision making, create logic controls systems.

An important application of fuzzy set theory is fuzzy logic controllers used in various control systems. These controllers use the integrated experts' knowledge that by the structure of representation approach to speaking and are described with linguistic variables and fuzzy sets.

The aim is to increase the efficiency of automatic control systems by using fuzzy logic.

THE MAIN STUFF

One of the main methods of knowledge representation in fuzzy logic systems are production rules that allow to get closer to the style of human thinking.

Usually, these production rules are given as "IF logical expression THEN operator", where the rule's condition (logical expression) is a statement about the content of the knowledge base, and the consequence (operator) suggests what we should do when this production rule is activated.

Summarizing the above said we can make a statement that the system of fuzzy logic is a system of following descriptions:

- fuzzy specification of parameters,
- fuzzy description of the input and output variables of the syst,
- fuzzy description of the system's functioning based on production rules "if-then".

The most important class of fuzzy systems are fuzzy control systems (fuzzy logic controllers).

The overall structure of fuzzy logic controllers (fuzzi-controllers) consists of:

- fuzzification block,
- knowledge base,
- fuzzy conclusion block,
- defuzzification block.

Graphically, this structure is shown in Figure 1.

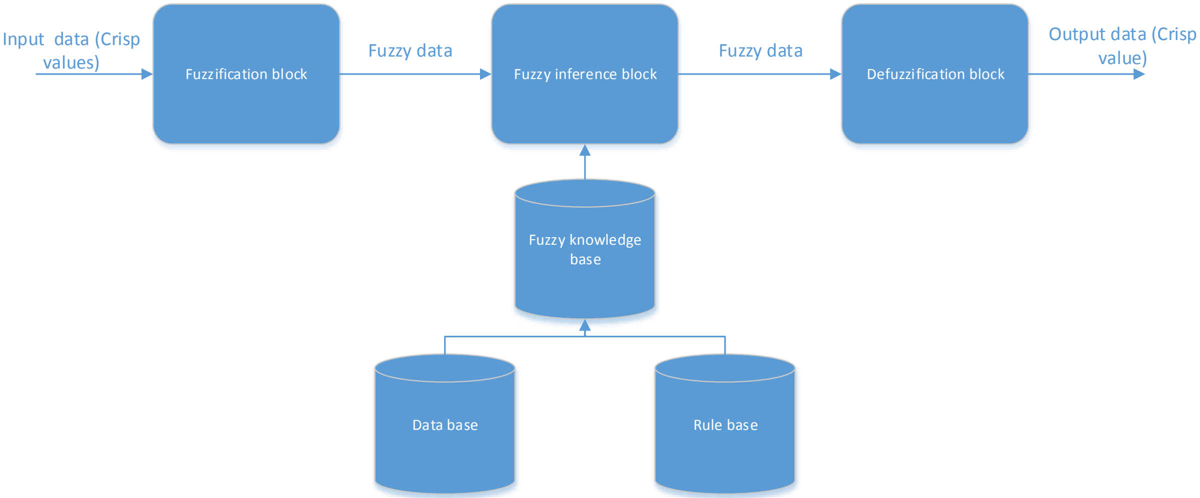

Fig. 1. The general structure of a fuzzi-controller

Fuzzification block turns precise values, measured at the output of control object, onto the fuzzy values, described by the linguistic variables in the knowledge base.

Fuzzy conclusion block uses fuzzy conditional (IF-then) rules incorporated in the knowledge base in order to convert fuzzy input data into the necessary control actions that are also unclear.

Defuzzification block converts the fuzzy output data block making a clear value that is directed to the execution unit to control the object.

The database contains functions of affiliation of fuzzy sets used in the fuzzy rules.

The rules base contains a set of fuzzy rules such as "if-then".

Due to that, the process of fuzzy logic controller can be determined by the following steps:

- fuzzification (transformation of clear input variables to fuzzy form, i.e. determining the coincidence grade of the inputs to each of the fuzzy sets),
- the proper logical conclusion (calculated value of truth for each rule condition),
- composition (combining of fuzzy rules outputs in the common notion),
- defuzzification (transformation of fuzzy rules output in a clear exit notion).

Fuzzy logic systems use linguistic variables to describe their own parameters of input and output variables. They reflect the experts' experiences, facts, qualitative information etc. and are expressed in terms of normative language.

Each linguistic variable is characterized by a set of terms that denote the set of qualitative states of a variable.

Suppose that a system which needs to improve the quality of management is characterized by a linguistic variable X that displays, for example, temperature and is characterized by a set of terms. Let X be defined m of linguistic terms:

$$X = \{A_j \mid j = 1..m\}, \quad (1)$$

where: A_j – term of fuzzy linguistic variable; m - total number of terms of fuzzy linguistic variable.

Each of the terms is a fuzzy set:

$$A_j = \{x, \mu_{Aj}(x) \mid x \; \varepsilon \; X,) \le \mu_{Aj}(x) \le 1\}, \quad (2)$$

where x – value of space of the input parameters of the system X; $\mu_{Aj}(x)$ - function (grade) of affiliation of each x set (terms) A_j.

Affiliation functions $\mu_{Aj}(x)$ of a linguistic variable X are defined in one measurement space X and put each real number x on the line segment [0,1]. In fact, this is a subjective measure of how an element x corresponds to the concept, the essence of which is formalized by a fuzzy set.

Inputs $x = (x_i \dashv \mid i = 1..n)$ and output y are clear controlled values. Each value x_i, $i = 1..n$ possess a fuzzy match as a linguistic variable $X = \{A_i \mid j = 1..m_j\}$.

Rules R_k, $k = 1..N$ check the meaning of each linguistic variable. Therefore, the maximum possible number of rules is: $N_{max} = \prod_{i=1}^{n} m_j$. In practice, the number of rules is not always necessary. The real number of rules $N \le N_{max}$.

Statement of a rule - a linguistic variable $Y = \{B_j \mid j = 1..m\}$, which takes the value of one of the terms B_j.

Generalizing of the rules is a composition of their fuzzy outputs into a single fuzzy set with its subsequent conversion to a precise output value y.

Fuzzification lies in convertion of precise input values $x = (x_1, x_2, ..., x_n)$ to the fuzzy set A '= (A', A ', ..., A').

During the fuzzification of precise input x_i grades of its compliance with each linguistic term are determined A_i, j along with the affiliation functions μ_{Ai}, j, $j = 1..m_i$. These degrees are the values of affiliation functions μ_{Ai}, j at the point $x = x_i$.

Fuzzy input values are transformed into output ones based on fuzzy logic rules.

Suppose that the control system performs conversion of values n input linguistic variables x = (x_i ┤ | i = 1..n) in output linguistic variable y = R (x) under the rules base R = {R_k ┤ | k = 1..N }.

Rules R represent menagement laws in the form of fuzzy implication R = A → B, which can be regarded as a fuzzy set in the Cartesian product of bearers of input and output fuzzy sets. The process of accumulation fuzzy result B` ¢ out of fuzzy input sets A` based on the knowledge A → B can be represented as follows:

$$B` = A` \cdot R = A` \cdot (A \rightarrow B), \quad (2)$$

where: - compositional rule of fuzzy inference.

In practice, for fuzzy inference a maximand composition is used, fuzzy implication is realized by finding the minimum affiliation functions. For the simulation of an expert system work according to the scheme of implication a fuzzy set of production rules is used, each of which is constructed as a conditional operator:

If - logical expression then - operator

where the logical expression - statements that are based on the basic logical operations over fuzzy values;

operator - the resulting solution.

Rules can determine the ratio of compliance (E) between the input linguistic variables X and their fuzzy terms {$A_{i,\ j}$ ┤ | i = 1, .., n; j = 1..m_j}. In general, a rule may include all possible combinations of linguistic terms for all input variables, combined by logical operations. In order to determine the fuzzy conjunction the defining of minimum can be used, and for fuzzy disjunction – defining of maximum of two affiliation functions.

Defuzzification output is used when fuzzy set of values of output linguistic variables is useful to convert into the precise ones.

There are a lot of methods of transition into the precise values: the method of the average center; first maximum; average maximum; altitudial defuzzification [7].

The method the average center or centroid method is to find the center of gravity (centroid) which is chosen as the output result:

$$Y = \frac{\sum_{j=1}^{m} y_j B^{/}(y_j)}{\sum_{j=1}^{m} y_j B^{/}(y_j)}, \quad (3)$$

where: B` (y_j) - the aggregate value of the system output after phase of logical inference, Y - the resulting value (the result of defuzzification).

In control systems resulting precise output value is used in a feedback loop to generate control actions.

The system can be used to control the operation of a diesel engine using electronic-controlled system [6]. The input values of the system are: engine temperature, engine rotation speed, accelerator pedal position, opacity of exhaust gases, pressure and temperature of the incoming air. The output value is the fuel supply of the engine (actually the fuel pump handle position). Simultaneously, the output value is used for feedback.

Let us construct a fuzzy model of functioning of the proposed system.

First of all, we have to define the input and output fuzzy linguistic variables:

- fuel supply: none, the minimum possible, reduced, optimal, increased, the maximum possible.
- engine rotation speed: starting, minimum, idling, high idling, speed of maximum torque, nominal, maximum.
- accelerator pedal: released, the minimally clicked, clicked, clicked the most. (Note, the same as for the speed).
- engine temperature: not heated, nominal (optimal), overheating, critical.

Let us create a rules base:

- If it is not heated enough and turns are higher than high idling then fuel supply is reduced.
- If it is not heated enough and the engine rotation is starting then fuel supply is increased.
- If the temperature is critical then the fuel supply is minimum possible.
- If the temperature is the most critical then the fuel supply is absent.
- If the accelerator pedal is released and turns are more than high idling then the fuel supply is absent.
- If the accelerator pedal is released and turns are high idling then fuel supply is minimum possible.
- If the accelerator pedal is maximum pressed and turns are minimum then fuel supply is maximum possible.

To calculate the output, the system step by step goes through the following stages: takes the results of measurements of engine monitoring devices, their fuzzification, actual logical conclusion, defuzzification of output fuzzy value and transfering it to the control circuit.

For hardware implementation of fuzzy logic, it is appropriate to use the motherboard of input\ output Arduino Mega 2560, which has its own programming environment and are fairly easy to reprogramme. The above-mentioned motherboard we use C-like language: Arduino Programming Language.

It is expected to improve technical and economic values of diesel engine using fuzzy logic methods by optimizing its fuel supply.

CONCLUSIONS

1. The model of fuzzy logic as a fuel supply system of diesel is presented, hardware and a list of inputs are specified.
2. The authors of this article didn’t use fuzzy logic to optimize the fuel supply.

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