A design and simulation of fuzzy PID controller for the optimization of temperature and humidity in the thermodynamic system

Štefan Koprda, Zoltán Balogh, Milan Turčani
Department of Informatics, Faculty of Natural Sciences
Constantine the Philosopher University in Nitra
Tr.A.Hlinku 1, 94974 Nitra
SLOVAKIA
skoprda@ukf.sk, zbalogh@ukf.sk, mturcani@ukf.sk

Abstract: The article describes modern methods of controlling for the optimization of continuous technological processes. Naturally, it is necessary to make provision for the level of technologies, which in recent times make use of the modern means of controlling. Characteristic feature of all of them is partial to complete decentralization of controlling from simple, two-level controlling, up to the fully decentralized controlling using LON (Local Operating Network) technologies. However, in all of them the common feature is the existence of a dispatcher (superior) level serving for the monitoring of technology, or for its optimization in the form of interventions of men into the control. By using the superior level for controlling we thus practically create an adaptive system capable of bringing the behavior of all the control system in line with the current state of the technological process, while preserving the process level of controlling.

Key-Words: fuzzy PID; fuzzy rules; Fuzzy Sets, optimization; Thermodynamic system; fuzzy control

1 Introduction

Proportional-Integral-Derivative (PID) control is a traditional linear control method used in many applications [1]. The PID controller algorithm is widely used for industrial automation tasks and thermal comfort heating and cooling applications where error, derivative of error, and integral of error are used in the calculation of control law [2].

Along with the development of computer technique we are currently more and more encountered with the infiltration of modern methods of controlling into the practice. Adaptive control, robust control and last but not least also the artificial intelligence and expert systems can serve as examples. An important part of artificial intelligence in the practice represents and will, from now on, represent fuzzy logic and its applications. Tzafestas and Papanikolopoulos [3] have indicated that exploitation of fuzzy logic allows for using the human approach to propose rule-based solutions for designing fuzzy FPID controllers.

It is applied especially in the areas, where it is impossible to make a mathematic description of the control system, or it is very complex and inapplicable for the purpose of control. Due to the fact that fuzzy logic utilizes the simple qualitative expression of heuristic knowledge of the human experts, fuzzy controllers have been proposed for a variety of systems [4] including energy systems.

Problems with modelling of continuous processes are obvious when solving multi-level control systems, where besides the extensive process level of controlling there exists also another level of controlling responsible for the continuous optimization of the process. While fuzzy logic has been used as an effective tool in development of F-PID control algorithm, the performance of these controllers is limited to the extent of possible combinations of fuzzy systems characteristics such as, fuzzy rules, membership functions, and input and output scaling factors examined heuristically based on empirical knowledge and experimental trial and errors by the human designer [5].

It is natural that it is necessary to improve quality of any production technology in a complex way, by replacing the technology itself, as well as by continuous optimization of operation, where it is inevitable to exploit not only exact theoretical means, but also practical experience, or heuristic procedures from the level of dispatcher control. It is just here, where new opportunities for exploitation of fuzzy controller are opening, as a compensation for a man in control and optimizing processes. Besides the already mentioned possibilities, the exploitation of fuzzy controllers in the practice is very widespread. For example, steam turbines control, chemical reactors and cement operations control have successfully been solved [6]. An example of a non-traditional exploitation can serve the use of fuzzy controller for the acceleration of the theory of neurone networks.

2 Arrangement of a measuring chain for the temperature and humidity adjustment in the thermodynamic system

Measuring chain consists of:

- Thermodynamic system of the first order,
- Temperature sensors,
- Humidity sensor,
- Heat source,
- Power supplies,
- Facility serving for temperature and humidity measurement named DN 20,
- Facilities for the measurement of consumption,
- Control programme, created in the programme MATLAB.

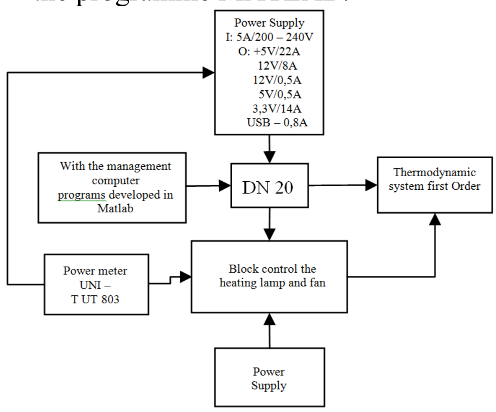

Fig. 1. Flow chart of the measuring chain

2.1 The design concept of the termodynamic system of the first order

The thermodynamic system was created by means of a wooden frame with the dimensions x=1.0 m, y=0.5 m and z=0.5 m. Thereafter, this frame was veneered from inside by an insulating plasterboard with the same dimensions as the size of the frame. The thickness of the insulating plasterboard is 1 cm. This frame was veneered from the outer side by polystyrene with the same dimensions as the frame. The thickness of the polystyrene is 5 cm. The volume of the system is 0.25 m^3.

2.2 Heat conductivity of insulating plasterboard

In this section we determined heat conductivity of the insulation plasterboard by means of the following relationship:

$$Q = \lambda \frac{S}{l}(t_1 - t_2)\tau \qquad (1)$$

The supplied heat is marked as Q, λ is heat conductivity to be determined, S is the board surface, l is the board thickness, t_1 - t_2 is the difference of temperatures at both sides and τ is the time during which heat Q is supplied. It is expected that the temperature difference is stabilized and that no heat is being lost.

The relationship can be adjusted as follows:

$$\lambda = \frac{Q}{\tau}\frac{l}{S(t_1 - t_2)} \qquad (2)$$

The fraction Q/ τ represents the supplied heat during the time period. If its source is electric heater elements, it is possible to substitute the output UI directly.

Thus we obtain:

$$\lambda = \frac{UIl}{S(t_1 - t_2)} \qquad (3)$$

The shape of the insulating plasterboard was cuboid with a square base with the side dimension 201 mm and thickness 13 mm. It was heated from one side by a foil with a resistance wire inside, powered up by a source with an alterable voltage and current. The board was cooled from the other side by water flowing through a metal cooler. The insulation plasterboard was separated from the foil and the cooler by a silicone heat foil. It was also equipped with incisions for thermoelements, by means of which temperature was determined on both sides. All this system was separated from the environment by polystyrene boards. Prior to the measurement itself it was necessary to calibrate thermoelements (to determine the dependence of voltage on the thermoelement on the temperature difference). This was done so that one end of the thermoelement was immersed in hot water, while the other was put aside with the surrounding temperature. Voltage of the thermoelement is directly proportional to the temperature difference on its ends.

$$U = \frac{1}{k}\Delta T \qquad (4)$$

Temperature of the environment was T_1 = 26.4 ºC, water temperature was T_2=82 ºC. Voltage on the thermoelement was U=2.34 mV. We thus obtain $k=(T_2-T_1)/U$ which equals 23.76 KmV^{-1}. Having determined properties of the thermoelement, the measurement itself was executed.

Heat conductivity of plasterboard λ=0.166 $Wm^{-1}K^{-1}$ (arithmetic average). For comparison we found in the catalogue heat conductivity of one kind of plasterboard, which was 0.113 $Wm^{-1}K^{-1}$, which is a lower value. This could have been caused by thermal losses, or different kind of plasterboard.

2.3 Finding out the transient characteristics of the designed thermodynamic system

Energy constantly flows through buildings and a building envelope plays the role of an interface between the inner and the outer space. The properties of a building envelope, especially of its transparent parts, have significant influence on interaction between the two spaces [7].

Before recording the temperature data in MATLAB the design marked DN 20 was used for the sensing of temperature and humidity. It is the device, which was designed at the Department of Electrical Engineering and Automation in cooperation with the firm Power – One s.r.o. [8]. The device consists of a microprocessor DN 20, connectors for the connection of temperature and humidity sensors, and outputs for controlling the heater element and a fan. Outputs are programmed and preset by means of the program MATLAB and allow for a fluent voltage control using PWM modulation on the connector output.

The device is connected to the computer with the serial port. In the computer runs the simulation program, which records, controls temperature and humidity and ensures controlling of the thermal source and fan in the thermodynamic system.

When finding out the transient characteristics we proceeded as follows. The thermodynamic system was heated by means of a 55 wat bulb. The time of heating was approximately 23.55 hours. Temperature sensors were deployed in the bottom and top parts of the system. For temperature sensing four temperature sensors marked Dallas DS18B20 were used.

The number of used sensors and their deployment in the thermodynamic system was verified by a series of experiments. Homogenous groups, or statistically significant differences in the temperature measured by the used sensors were identified using an analysis of experimental data. Individual experiments differed by the number of sensors and their deployment. When processing the experimental data we were inspired by [9, 10, 11].

Table 1 Multiple Comparison (Tukey HSD Test)

SENSOR	Mean	1	2	3	4
temperature2	27,61241	****			
temperature1	27,87892		****		
temperature5	27,88321		****		
temperature3	27,97136			****	
temperature4	28,16232				****

From the multiple comparison one homogenous group (temperature1, temperature5) was identified. In case of the other sensors statistically significant differences in the obtained temperatures were proved. Exploitation of four sensors in our system turned up satisfactory.

Sensors, which were situated in the system, were connected to the device, which controlled microprocessor device DN 20. The device was connected with the computer, on which the program MATLAB with the created control program for the given measurement was running.

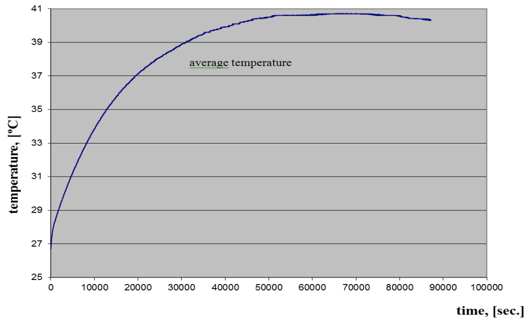

Fig. 2. Real transient characteristics measured

Equation of this thermal system will look like:

$$G(p) = \frac{K_P}{Tp+1} \qquad (5)$$

where T – will be calculated as $\left(1-\frac{1}{e}\right)$ multiple of the final value,

Kp – is the final value,

p - Laplace operator,

e - Euler´s number

For the calculation of T the mean characteristic was used. T = 14290 s

KP = 1

Simulation of the transient characteristics of the system

$$G(p) = \frac{1}{14290s+1} \qquad (6)$$

The following orders will be used for finding the transient characteristics in the program MATLAB:

```
sys = tf(1,[14290  1])
step(sys)
```

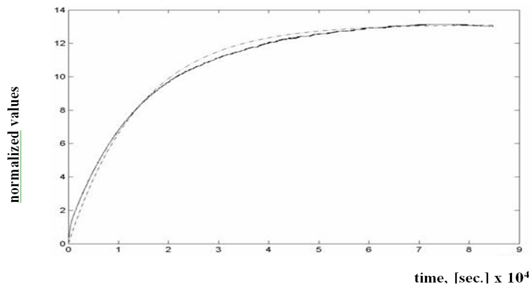

Fig. 3 Resultant characteristics of the real and simulated transient characteristics – Similarity is 99.77 %.

3 Proposal of fuzzy control of temperature and ventilation in the thermodynamic system of the first order

Proper functioning of the control algorithm is essential for adequate adjustment and velocity of the roller blind alternations. Control algorithms with fuzzy controllers offer better response and efficiency in case of complex nonlinear and time varying working conditions when compared to conventional PID controllers. The advantage of the fuzzy controller's design derives from its similarity to human reasoning [12].

Thermodynamic system was described by a two-dimensional fuzzy system with a single output MISO (multi input, single output). Input variables are temperature and relative humidity, which belong among basic descriptive traits of air exchange, while the output variable is the signal for continuous control of the heater element and fan revolutions. In the process of passive ventilation air with variable basic features from external or internal environment is used.

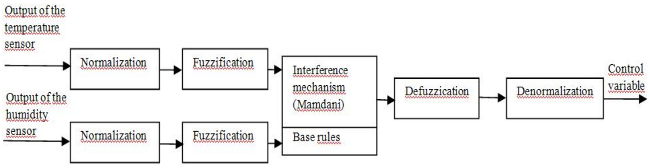

Fig. 4. Block structure of the designed general fuzzy control system

Fuzzy controllers, in the application of fuzzy sets theory [13,14], have some special characteristics that other controllers lack or do not have. First of all, they provide systematic and efficient means of capturing the linguistic fuzzy information from the human experts or the real world. Next, they can convert the linguistic control strategy into an automatic control strategy that is nonlinear and model-free. Practically, the fuzzy control is easy to understand and simple to implement, because it emulates the human control strategy. Thus it has been reported recently that a lot of fuzzy controllers are able to control such systems that are very complex or poorly modeled and that experienced human operators are available for providing expert rules [15, 16].

The control system consists of three main sections: fuzzification, interferential mechanism and defuzzification. One part of fuzzification converts the real exact values into a fuzzy expression, while fuzzy interferential mechanism evaluates the input data and calculates the output value based on the base of knowledge and the database. These fuzzy values of outputs are converted into real values in the process of defuzzification.

Generally, a control system, which is capable of implementation in a various system of ventilation and a different construction design concept, was proposed.

We expected exploitation of linear sensors. The function of adherence of the input variable (temperature) was mapped into the normalized universum [-1, 1], the function of adherence of the input variable (humidity) was mapped into the normalized universum [-3, 3], the function of adherence of the output variable (signal for the control of heater element and fan) was mapped into the normalized universum [-100, 100] and subsequently fuzzified. The functions of adherence of the input variables and the output variable are in figures 5, 6 and 7.

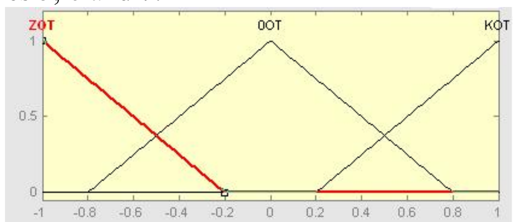

Fig. 5 Function of adherence of the input variable (temperature)

$$OT = T_{REQ} - T \quad (7)$$

OT – temperature deviation
T_{REQ} – required temperature
T – input temperature
ZOT – negative temperature deviation
0OT – zero temperature deviation
KOT – positive temperature deviation

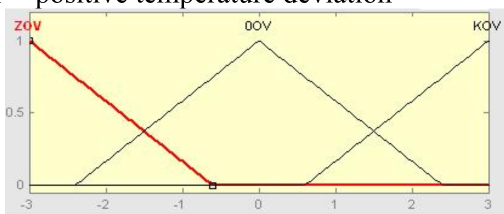

Fig. 6 Function of adherence of the input variable (humidity)

$$OV = V_{REQ} - V \quad (8)$$

OV – humidity deviation
V_{REQ} – required humidity
V – input humidity
ZOV – negative humidity deviation
0OV – zero humidity deviation
KOV – positive humidity deviation

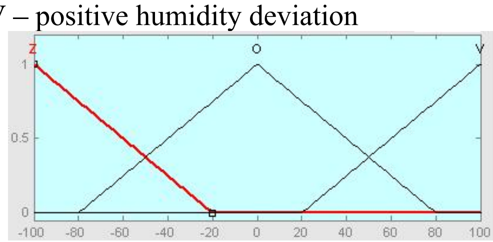

Fig. 7 Function of adherence of the output variable (heater element and fan control)

Z – bulb
O – zero
V – ventilator

Distribution of functions of adherence of the output control variable is again in the normalized interval, while their shape is formed by sharp lines on the given position of the verbal value in consequence of the decision rules, so-called singletons. In fact, this means that the value (0, -100) represents the value, during which it is an active heater element and the value (0, 100) represents the value, during which it is an active fan.

If/then rules offer a convenient format for expressing pieces of knowledge. But it is just a format which can cover different intended semantics and uses. The consequent of a rule may be qualified with various modalities expressing, for instance, strong ones such as certainty, obligation, or weaker ones such as possibility or feasibility. Rules may have implicit exceptions, or may universally hold. Depending on their interpretation, rules have to be represented and processed in a specific way at the inference level [17].

Fuzzy logic control of the system operates on the basis of implication of two fuzzy statements. If ascendent then consequent *(by means of an implication of the Mandami alternative If <fuzzy statement> then <sharp ascending value>)*. A fuzzy linguistic model with the following hierarchy was used:

1. If (OT is ZOT) and (OV is ZOV) then (u is V)
2. If (OT is ZOT) and (OV is 0OV) then (u is 0)
3. If (OT is ZOT) and (OV is KOV) then (u is 0)
4. If (OT is OOT) and (OV is ZOV) then (u is V)
5. If (OT is OOT) and (OV is 0OV) then (u is 0)
6. If (OT is OOT) and (OV is KOV) then (u is 0)
7. If (OT is KOT) and (OV is ZOV) then (u is V)
8. If (OT is KOT) and (OV is 0OV) then (u is Z)
9. If (OT is KOT) and (OV is KOV) then (u is Z)

When choosing the rules, quantitative expert knowledge supported by theoretical knowledge based on vague input information, were used. It is necessary to provide conditions of completeness, consistency, continuity and interaction of the set of rules. Local changes can be obtained by alternation of the consequent of the appropriate rule and the size of the area, where the change will be realized, can be influenced by the width of fuzzy sets.

The whole base of knowledge of the fuzzy control system was filled up by means of the graphic user interface and using the means - Matlab® program - Fuzzy Logic Toolbox into the corresponding universes. The fuzzy control system results in a non-linear control area depicted in the figure 8.

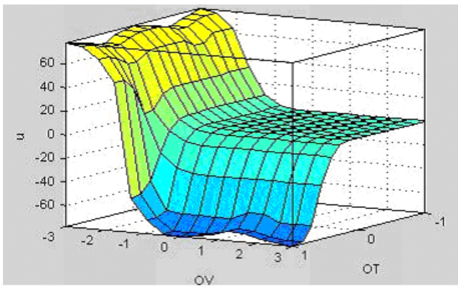

Fig. 8 Generated control area of the designed system

Having finished the design of the fuzzy control, it was inevitable to connect the fuzzy controller with the system in order to practically verify the function of the controller. For the provision of sensing the input quantities (temperature and humidity) and the consecutive control up to the selected value the microprocessor device DN 20, which was described in the previous chapters, was used again. For the interconnection of the designed fuzzy controller with the microprocessor device DN 20 and the thermodynamic system a control scheme in the program MATLAB was created. The control scheme consists of the block Write read format, Write format and the block Processing. The control scheme is in figure 9.

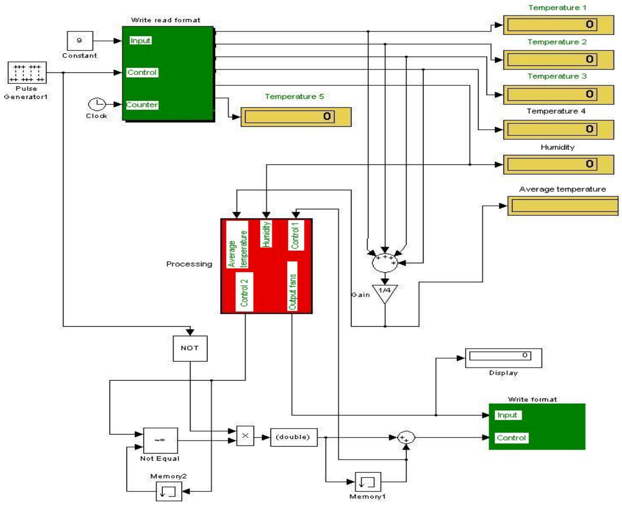

Fig. 9 Control scheme

The most important part of the control scheme is the Processing block. The Processing block contains the defined fuzzy controller and a selector, which, as need may be, provides control of the heater element or fan. The Processing block scheme is shown in figure 10.

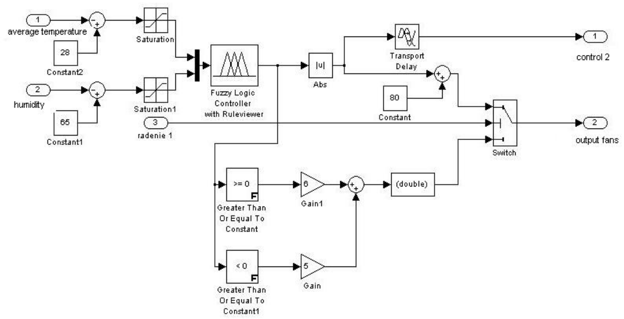

Fig. 10 Block scheme of the Processing block

In the Processing block we can also set up the required value of temperature and humidity in the thermodynamic system.

In our case we set up temperature to the value 28 ºC and relative humidity to 65 %. The obtained results are presented in figures 11 and 12.

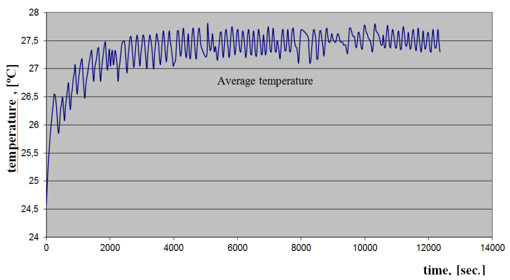

Fig. 11 Course of temperature using fuzzy control

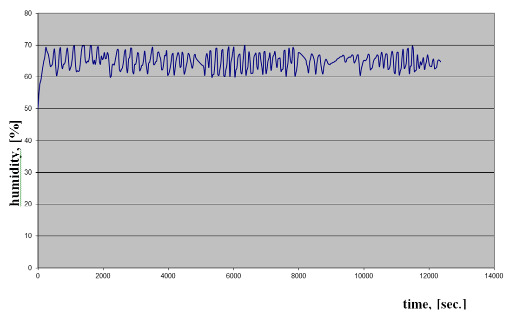

Fig. 12 Course of humidity using fuzzy control

4 Discussion

The period of measurement was 3.4 hours and the period of sampling lasted for 30 s. The initial value of temperature was 24.73 ºC and humidity 48 %. In the course of measurement temperature oscillated within the range of 27.4 ºC to 27.78 ºC. When comparing with the required value of temperature we can state that the range of temperature was 0.6 ºC. The value of humidity oscillated within the range of 60 up to 69.8 % when compared with the required value, which means that the controller was capable of controlling humidity with the ± 5 % accuracy.

Then, we can say that besides the natural external interference, the design of the fuzzy logic control system is influenced also by the factors of shape and distribution of the input and output functions of adherence, the used interference rules and the selected values of measures. Practically, the setting of controller is most frequently done by alternating the sizes of measures, by which it is possible to shift the value of the control intervention into the required position on the control area, thus reaching the adequate value of its size.

In the future, the above mentioned control system could be extended by an implementation of genetic algorithms.

5 Conclusion

The article deals with the issue of temperature and humidity control using a fuzzy controller. The used algorithms of the two-state and PSD control can control only one of the required value of ambient conditions.

The designed fuzzy controller is capable of controlling two or more parameters and can be used for the optimization of technology, which contains the superior level of controlling, while allowing for the access to the operator´s knowledge. Characteristic feature of the used approach is also the elimination of unwanted interferences of a less experienced operator, as an indefinite element in the control upon optimizing the process.

Contribution of this article can be found also in creating the program practically allowing for exploitation of the level of control for the optimization of various continual processes using fuzzy controllers, creation of the model of thermodynamic system, on which it is possible by means of simulation to verify the qualities of the two-state, PSD and fuzzy control and possibilities of their exploitation upon optimizing the parameters of controllers and optimization of consumption of electric energy of the designed controllers.

References:

[1] A. Prodic, D. Maksimovic, Design of a digital PID regulator based on look-up tables for control of high-frequency dc–dc converters, in: Proceedings of IEEE Workshop on Computers in Power Electronics, 2002, pp. 18–22.

[2] Ardehali MM, Saboori M, Teshnelab M. Numerical simulation and analysis of fuzzy PID and PSD control methodologies as dynamic energy efficiency measures. Energy Convers Manage 2004;45(13–14):1981–92.

[3] Tzafestas S, Papanikolopoulos NP. Incremental fuzzy expert PID control. IEEE Trans Ind Electron 1990;37(5):365–71.
[4] Shepherd AB, Batty WJ. Fuzzy control strategies to provide cost and energy efficient high quality indoor environments in buildings with high occupant densities. Build Services Eng Res Technol 2003;24(1):35–45.
[5] Linkens DA, Nyongesa HO. Genetic algorithms for fuzzy control part1: offline system development and application. IEE Proc Control Theor1995;142(3):161–85.
[6] Frey, W.- Sajidman, M.- Kuntze, H. A Neuro-fuzzy Supervisory Control System for Industrial Batch Processes. The Ninth IEEE International Conference on Fuzzy Systems, San Antonio, Texas, 2000, :116-121.
[7] Krainer A. Building science and environment-conscious, design module 1: Design principles, 7 toward smart buildings. European Commission TEMPUS Joint European Project JEP-1802, 1993.
[8] Amrich, M, Hrubý, D., Simulation options and design of fuzzy control algorithms. In: International Professional Seminar Topical Questions of Instruction of Electricaal Engineering Subjects at Faculties with Non-electrical Orientation“ SEKEL ´06. September 12 – 14, 2006, Vrátna, Slovakia. s. 29-33. ISBN 80-8070-584-4.
[9] Munk, M., Kapusta, J. & Švec, P. (2009). Data preprocessing dependency for web usage mining based on sequence rule analysis. IADIS European Conference on Data Mining 2009, ECDM'09, Algarve, pp. 179-181. ISBN 978-972-8924-88-1.
[10] Munk, M., Kapusta, J., & Švec, P. (2010). Data Preprocessing Evaluation for Web Log Mining: Reconstruction of Activities of a Web Visitor. Procedia Computer Science, Vol. 1, No 1, pp. 2267-2274. ISSN 1877-0509.
[11] Michal Munk, Marta Vrábelová, Jozef Kapusta. Probability modeling of accesses to the web parts of portal. Procedia Computer Science, Volume 3, 2011, Pages 677-683, ISSN: 1877-0509
[12] Babuska R, Verbruggen HB. An overview of fuzzy modeling for control. Control Eng Pract 1996;4(11):593–606.
[13] D. Dubois and H. Prade, Fuzzy Sets and Systems: Theory and Applications (Academic Press, Orlando, FL, 1980).
[14] H.-J. Zimmermann, Fuzzy Set Theory - And Its Applications (Kluwer, Dordrecht, 1991).).
[15] C.C. Lee, Fuzzy logic in control systems: fuzzy logic controller Parts I and II, IEEE Trans. Systems, Man and Cybernet. 20 (1990) 404-435.
[16] M. Sugeno, Industrial Application of Fuzzy Control (Elsevier, Amsterdam, 1985).
[17] D.Dubois and H.Prade, What are fuzzy rules and how to use them, Fuzzy Sets and Systems 84 (1996) 169 -185