Yao Yueqin

Zhao Guoliang

DESIGN OF THE FUZZY METHANE CONCENTRATION CONTROL SYSTEM BASED ON FPGA

DOI 10.15589/SMI20170202

Yao Yueqin undergraduate, associate professor, Bachelor of Automation
553053001@qq.com

Zhao Guoliang Master of Control Theory and Control Engineering
330176382@qq.com

Yancheng Institute of Industry Technology, Yancheng City, Jiangsu 224005, PR China

Abstract. A fuzzy control system for measuring methane concentration has been designed on the basis of FPGA. The fuzzy control algorithm and establishment of the fuzzy control rules are considered in detail, and implementation of the fuzzy control system is realized based on FPGA. Compared with traditional control methods, the system has a high control accuracy and unobvious hysteresis

Keywords: FPGA; fuzzy control; measurement of methane concentration.

References

[1] Peraza C., Valdez F., Castillo O. An adaptive fuzzy control based on harmony search and its application to optimization [M]. Nature-Inspired Design of Hybrid Intelligent Systems. Springer International Publishing, 2017.

[2] Zhou Q., Wang L., Wu C., et al. Adaptive fuzzy control for nonstrict-feedback systems with input saturation and output constraint [J]. IEEE Transactions on Systems Man & Cybernetics Systems, 2017, 47(1):1-12.

[3] Stan S. D., Bălan R., Mătieş V., et al. Kinematics and fuzzy control of ISOGLIDE3 medical parallel robot [J]. Canadian Review of American Studies, 2016, 36(3):273-291.

[4] Chen B., Lin C., Liu X., et al. Observer-based adaptive fuzzy control for a class of nonlinear delayed systems [J]. IEEE Transactions on Systems Man & Cybernetics Systems, 2016, 46(1):27-36.

[5] Li H., Wu C., Yin S., et al. Observer-based fuzzy control for nonlinear networked systems under unmeasurable premise variables [J]. IEEE Transactions on Fuzzy Systems, 2016, 24(5):1233-1245.

[6] Pan I., Das S. Fractional order fuzzy control of hybrid power system with renewable generation using chaotic PSO [J]. Isa Transactions, 2016, 62:19-29.

[7] Zhou Q., Li H., Wu C., et al. Adaptive fuzzy control of nonlinear systems with unmodeled dynamics and input saturation using small-gain approach [J]. IEEE Transactions on Systems Man & Cybernetics Systems, 2016, PP(99):1-11.

[8] Radgolchin M., Moeenfard H., Ghasemi A. H. A two-level adaptive fuzzy control algorithm for beyond pull-in stabilization of electrostatically actuated microplates [C]. ASME 2016 Dynamic Systems and Control Conference. 2016.

[9] Petković D., Shamshirband S., Anuar N. B., et al. Input displacement neuro-fuzzy control and object recognition by compliant multi-fingered passively adaptive robotic gripper [J]. Journal of Intelligent & Robotic Systems, 2016, 82(2):177-187.

[10] Wang F., Liu Z., Zhang Y., et al. Adaptive fuzzy control for a class of stochastic pure-feedback nonlinear systems with unknown hysteresis [J]. IEEE Transactions on Fuzzy Systems, 2016, 24(1):140-152.

[11] Padmanaban S., Blaabjerg F., Martirano L., et al. PI and fuzzy control strategies for high voltage output DC-DC boost power converter – Hardware implementation and analysis [C]. IEEE, International Conference on Environment and Electrical Engineering, 2016.

[12] Chang W. J., Kuo C. P., Ku C. C. Fuzzy control via imperfect premise matching approach for discrete Takagi-Sugeno fuzzy systems with multiplicative noises [J]. Journal of Marine Science & Technology, 2016, 24(5):949-957.

[13] Bouzeriba A., Boulkroune A., Bouden T. Projective synchronization of two different fractional-order chaotic systems via adaptive fuzzy control [J]. Neural Computing & Applications, 2016, 27(5):1349-1360.

[14] Fu J., Li P., Wang Y., et al. Model-free fuzzy control of a magnetorheological elastomer vibration isolation system: analysis and experimental evaluation [J]. Smart Material Structures, 2016, 25(3):035030.

Problem statement. Safety is a top priority in coal mining, and gas explosion is the biggest hazard in the sphere. Therefore, it is very important to design a gas concentration detection and control system with a high precision and hysteresis. Compared to a traditional control strategy in MCU, FPGA has the advantage of a high data-processing speed. The accuracy of the system with FPGA as the main controller is greatly increased, and lagging of the system is greatly reduced. It can effectively detect and control gas concentration, which ensures the safety of the mine. With multiple I/O interfaces of FPGA, the system scalability is greatly increased, whereas only one FPGA is used as the main controller in the variety of detection systems. Compared to a traditional measurement strategy with one testing equipment for one system, the difficulty of the PCB board system and the production cost of the circuit are greatly reduced. It is beneficial for the improvement of the enterprise economic efficiency.

The traditional control strategy is built on the accurate system transfer function. However, it is difficult to achieve, even if one can get the system transfer function, since some variables are not necessarily measurable. Thus, the system can not always meet the requirement of control accuracy and response time. With the fuzzy control method, unlike traditional means of control, accurate system transfer function is not necessary in the control system. Corresponding control rules can be designed according to the requirements of the system and control experiences. The method of fuzzy control design is much easier compared to the traditional one. Because of the control method built by Verilog HDL language, when the system parameters are changed or the control strategy is ported to other systems, one can simply download the control rules to the FPGA. It reduces the cycle of system development and control costs.

Basic material.

1. Implementation of fuzzy control system

Gas concentration and change rate are used as input parameters in the system. 500Hz modulation signal duty ratio is labeled as the output. The whole control system is a dual input and single output fuzzy control system. Block diagram of the system is shown in Fig. 1.

As a result of performing the fuzzy control algorithm in the system, selection of the system control strategy is in the MCU, so the circuit is simpler than that of the traditional strategy. When the system is activated, the gas concentration detector fulfills its purpose and outputs a millivolt level voltage signal proportional to the gas concentration. This electrical signal is transmitted to the A/D converter after filtering and amplification. The converted data is sent to the FPGA. The controller translates the voltage concentration based on the binary number of the input voltage and then outputs modulation signal to control an exhaust motor based on fuzzy control rules. The hardware component of the system is shown in Fig. 2.

The flammable catalyzing gas sensor MJC4/3.0L is used to detect gas density. The sensor is paired with the detecting element to make up two arms of the bridge. The resistance of the detector increases as a reaction to a flammable gas, and the output voltage of the bridge changes. The voltage increases with the increase of gas concentration, and there is a component for temperature and humidity compensation. The basic properties are as follows: linear output voltage of the bridge; quick response; good repeatability; stable and reliable components; resistance to H_2S poisoning.

As shown in Fig. 3 of the sensor sensitivity curve, when gas is measured with the concentration of 0~3%, the output voltage of the sensor is 0~65 mV, the entire voltage output is linear, which meets the design requirements of the system.

EP2C5Q208C8N is used as the main controller of the system. It is a cost-effective FPGA control chip lunched by Altera. It is a new type of a high-density PLD with the CMOS–SRAM process. It consists of a number of independent programmable logic modules that can be flexibly connected to each other and can form complex digital systems on a single chip. Because of the complex environment of the mine, it is necessary to

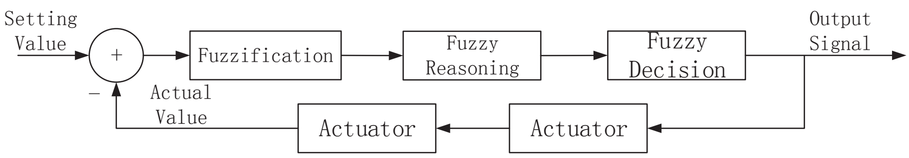

Fig. 1. Block diagram of the system

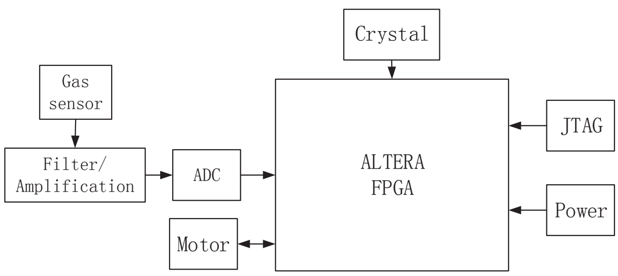

Fig. 2. Hardware component of the system

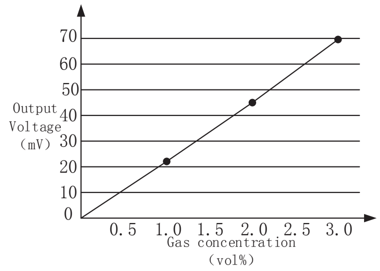

Fig. 3. Sensor sensitivity characteristic curve

use more sensors to detect such signals as temperature, humidity and gas concentration. The traditional design scheme is one control chip for one system, which is not conducive to the management and maintenance of the system and increases the operation cost of the enterprise. On the contrary, in the FPGA as the main controller, because of many I/O ports, only one chip can be used for all signal detection and control. At the same time, the speed of FPGA processing data is at a decent level, so even for high-speed bit flow signals, such as audio and video ones, the FPGA can also be fully qualified. Based on the above, the advantages of using the FPGA as the main control chip, the whole system is highly integrated and has a high data-processing ability, the enterprise expenses is saved, and the delay of the system is greatly reduced.

2. Implementation of fuzzy control algorithm

According to the basic indicators of gas extraction in coal mines (AQ1026-2006) published by the state administration of production supervision and administration (dated November 2, 2006), the gas concentration of the mine in the mining process shall not exceed 1% of the gas content. Therefore, the system only controls the part of over 1% of the gas concentration.

2.1. Blur the concentration deviation

As shown in formula 1, the concentration error is defined as P_0 subtract P_t. Since the concentration range in the mine is set between 0~1%, the measurement range of the sensor is 0~3%, so the universe of concentration deviation error is [0%, 2%]. It is divided into 11 fuzzy subsets, and the relation of concentration errors to the corresponding fuzzy subsets is shown in Table 1.

$$\text{error} = P_0 - P_t, \quad (1)$$

where P_0 is the setting concentration, and P_t is the measured concentration

2.2. Fuzzy measure of concentration change rate

As shown in formula 2, the concentration change rate is defined as the value of the gas concentration change in the well in unit time. In this system, sampling time is set as 1 s; the gas concentration of the mine is detected every second.

$$\text{Rate} = (P_t - P_0)/t = \text{Error}/t \quad (2)$$

The basic universe of the rate is set as [–0.06, +0.06], it is divided into 7 fuzzy subsets. The relation between the fuzzy subsets and the corresponding concentration rates is shown in Table 2.

2.3. Blur of system output

The system can adjust the wind speed of the fan by the output of the electrical signal ratio. Its basic universe is [0,100%], it is divided into 11 fuzzy subsets. The relation between the fuzzy subsets and the duty cycles is shown in Table 3.

2.4. Establishment of fuzzy control rules

The control rule of the dual-input single-output system is "If error and rate then ratio"; according to the control rules of fans in the mine, the fuzzy control rules are shown in Table 4.

Table 1. Error blur of concentration difference

Error	Fuzzy results	Error	Fuzzy results
0	0	[1.0,1.2]	P5
[0,0.2]	P0	[1.2,1.4]	P6
[0.2,0.4]	P1	[1.4,1.6]	P7
[0.4,0.6]	P2	[1.6,1.8]	P8
[0.6,0.8]	P3	[1.8,2.0]	P9
[0.8,1.0]	P4		

Table 2. Concentration rate blur

Error	Fuzzy result
[–0.06, –0.04]	NL
[–0.04, –0.02]	NM
[–0.02,0]	NS
0	0
[0,0.02]	PS
[0.02,0.04]	PM
[0.04,0.06]	PL

Table 3. Ratio blur

Ratio	Fuzzy result	Ratio	Fuzzy result
0	0	[50%,60%]	P5
[0%,10%]	P0	[60%,70%]	P6
[10%,20%]	P1	[70%,80%]	P7
[20%,30%]	P2	[80%,90%]	P8
[30%,40%]	P3	[90%,100%]	P9
[40%,50%]	P4		

Table 4. Fuzzy control rules of the duty cycle

Rate	Error										
	0	P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
NL	0	P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
NM	0	P0	P0	P1	P2	P3	P4	P5	P6	P7	P8
NS	0	P0	P0	P0	P1	P2	P3	P4	P5	P6	P7
0	0	P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
PS	P0	P1	P2	P3	P4	P5	P6	P7	P8	P9	P9
PM	P1	P2	P3	P4	P5	P6	P7	P8	P9	P9	P9
PL	P2	P3	P4	P5	P6	P7	P8	P9	P9	P9	P9

3. Software design

Verilog HDL language is used in software development. It is a formalized description language for digital circuits and systems; it is also one of the most widely used hardware description languages. It is suitable for system level, algorithm level, register transmission level, logical level and other design. Compared with traditional hardware description languages, Verilog HDL is intuitive and easy to master.

The concentration difference error in the design is realized by means of the macro module parametric addition/subtraction device called “lpm_ add_ sub”. The concentration rate is transferred by a parallel 10 bit synchronous register “P10_register”. The trigger clock “clk” is set to 1KHz. When rising edge of clk arrives, the current concentration error “error(t)” is stored in the register. Before the third rising edge, the concentration error of the first two times error($t-1$) and error(t) are available; with “lpm_ add_ sub”, the concentration error rate is available.

The table of fuzzy rules is solidified in the ROM named LPM_ROM through program writing. The ROM address line width for LPM_ WIDTH is set to 8, of which 4 are for high concentration deposit deviation error, and 4 are for low concentration storage change rate. The fuzzy control table is written in the form of code, in the configuration data file of ROM, named "ROM_ data".

4. Simulation result

The gas concentration control system is simulated as a two-order system, so the simulation result can be obtained with a second-order system shown in formula 3.

$$G(s)=\frac{s+10}{s^2+6s+8}e^{-2Ts}; \qquad (3)$$

The unit step function is used as input in the simulation system. The system is built with the help of Simulink tool box in MATLAB; the block diagram of the system is shown in Fig. 4.

The simulation result is achieved when the unit step function is used as input in the system simulation. As shown in Fig. 5, a high reaction speed is achieved in the system when the input concentration is 2%. The control system reaches the predetermined concentration of 1% in 3 s with a smaller overshoot. The simulation result shows that it is suitable for use in mines with complex environment.

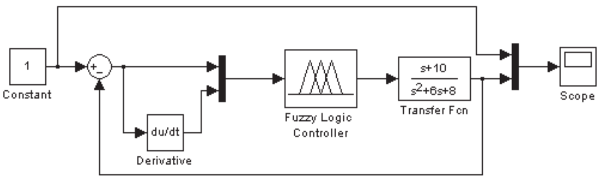

Fig. 4. Block diagram of the system

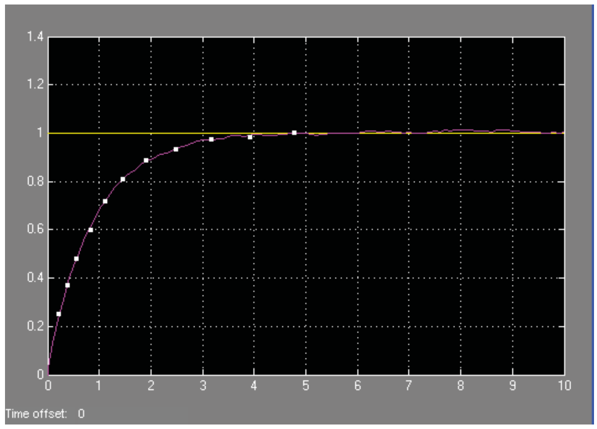

Fig. 5. Simulation of fuzzy control system

CONCLUSIONS. In the view of the complex detection environment under the mine, there has been designed a fuzzy gas concentration control system based on FPGA. The simulation of the system has been carried out, and the result shows that the system can fully meet the design requirements with a good reaction speed and minimum hysteresis. With the method of control rules written in ROM, the system operates accurately under control. By changing the fuzzy control rules, the system can be applied to other purposes of signal detection without the need to adjust the system greatly. The portability of the system is greatly improved. Based on the advantages of the FPGA multi I/O port, other signal detection systems can be connected to FPGA control, so that the degree of integration of the downhole monitoring system is greatly improved as well.

Статью рекомендует в печать
д-р техн. наук, проф. *Г. В. Павлов*