MONITORING SPEED OF DC MOTOR USING FUZZY PID CONTROLER VIA WEB SERVER

Dao Vu Anh, Dan Bui Thi
Posts and Telecommunications Institute of Technology, Hanoi, Vietnam

Abstract: The use of PI, PD, and PID controllers to control variable-speed motors is difficult to satisfy the system's stability requirements. Therefore, adding fuzzy to adjust PID parameters is a new direction for automatic control systems to improve their quality. In this paper, we propose a system using fuzzy PID controller, STM32F103C8T6 microcontroller, ESP8266 wifi module to monitor DC motor speed and some parameters to evaluate the quality of the system through web server. System simulation on Matlab-Simulink confirms the effectiveness of this controller.

Keywords: PID, fuzzy PID; DC motor, web serve

I. INTRODUTION

A common problem in the field of control and automation is to control the speed of the DC motor precisely, stably, and respond quickly... because DC motors are used in many industrial and household devices.

Proportional Integral (PI), Proportional Derivative (PD) and Proportional Integral Derivative (PID) Controller are some controllers widely used in industry. PID controller has a long history in the field of control - automation. James Watt introduced the first negative feedback system in 1769 and it was mathematically modeled by J. C. Maxwell in 1868 [1-3]. Later, Nicolas Minorsky gave a theoretical analysis for the derivative of the error - its rate of change [2]. Minorsky's contribution is the foundation of modern PID controllers. Elmer Sperry deployed the first PID controller in 1911 for the US Navy [3,4]. After many years, the existing problems of the controller have been troubleshooted. For example, the setting error of the proportional controller is handled by the integral step, the over-shooting is handled by the differential step. However, designers still could not find the exact parameter for PID controller until 1942, when Zieglers and Nichols introduced method of parameter selection for PID controller in different cases. The PID controller was widely used in industry in the mid-1950s [5]. In the later stage, the PID controller is integrated with more features such as self-adjusting parameters [6,7], optimal PID [8], adaptive PID [9], fuzzy PID [10-12]...

Contact author: Dao Vu Anh,
Email: daova@ptit.edu.vn
Manuscript received: 7/2023, revised: 8/2023, accepted: 9/2023.

Even though, there have been many new control methods discovered by reseachers, PID is favoritedly used in controllers. The fact is, although PID often do not achieve optimal performance, it can guarantee satisfactory results for many technological processes. Due to its simple structure, it is often considered the best solution based on quality and cost.

Internet of Things (IoT) provides integration and interaction between extensions, technologies or products across multiple networks, focus on control schemes. Smart IoT devices can play flexible connectors with changeable architecture, which allowing for fast response and universal access. In control systems, IoT is extensively utilized [13-15], from automatic door systems, self-driving cars to aircrafts. It allows communicatting real-time data without human involvement.

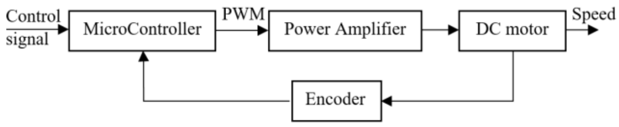


Fig. 1 Block diagram of speed monitor system of the DC motor

The armature voltage variation method is commonly used to control the speed of a DC motor. PWM technique to control motor speed is selected by the authors. With this method, the voltage supplied to the power amplifier remains constant, but it’s output voltage to the DC motor changes according to the control algorithm.

As shown in Fig. 1, the microcontroller plays the most important role. It receives the control signal from the main board, the feedback signal from the motor through the encoder to calculate the necessary PWM value to output of the power amplifier to control the motor to the desired speed and position.

Power amplifier block provides the accurate voltage to control the motor based on the processing and calculation of the microcontroller. Depending on speed of the motor, we must design this block suitably.

The encoder mounted on the motor provides information about the it’s current state to the microcontroller. The higher the encoder resolution, the better the control quality. However, a high resolution encoder also requires a higher processing power of the microcontroller.

The paper proposes a system using fuzzy PID controller for processes with diminishing response, this allows determinning scaly, integral and differential coefficients through fuzzy inference system and quality monitoring system over the web. The main goal of this approach is to improve system performance, i.e. reduce uptime, overshoot, and response time. The goal of fuzzy logic is improving system performance when the objects change.

The rest of this paper is arranged as follows. Section II shows some theoretical bases as PID controller, fuzzy PID controller, DC motor, microcontroller STM32F103C8T6… System design steps are provided in section III. The results of the proposed system are presented and discussed in section IV. Finally, section 5 closed the paper with some relevant conclutions.

II. THEORETICAL BASIS

A. *PID controller*

Fig. 2 is block diagram of control system using a typical PID controller (this is also the most ideal form of a PID controller). The control signal $u(t)$has the equation:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de}{dt} = K_C \left(e(t) + \frac{1}{T_I} \int_0^t e(t)dt + T_D \frac{de}{dt} \right) \quad (1)$$

Where $K_p = K_C$ is the proportional gain, $T_I = K_c / K_i$ is the integral time, and $T_D = K_d / K_C$ is the derivative time.

In terms of time, P depends on the current deviation, I depends on the accumulation of past deviations, and D predicts future deviations based on the current rate of change. If the coefficient K_p is big, the system is less stable. Otherwise, the system is less sensitive or it slow down the response. The integral component (incorporating with proportional component) increases the speed of the system to the setting point, overshooting and eliminates the error. The differential component is used to reduce the overshooting generated by the integral component and improve the stability of the controller. However, the derivation of a signal amplifies noises, therefore, this component is more sensitive with noises in the error, and it can make the system unstable if noises and differential gain are big enough. Therefore, choosing a suitable set of parameters for the PID controller is essential.

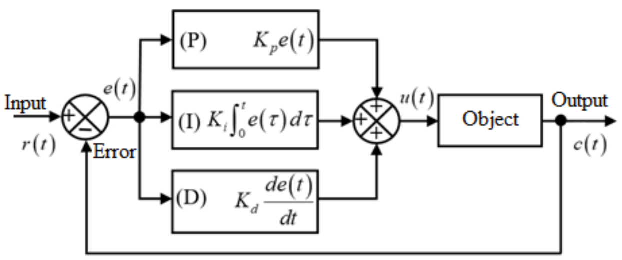


Fig. 2 Block diagram system control using PID

Table. 1 lists the influence of controller parameters on system quality. With the method Zieglers - Nichols [16], it is not difficult to find the optimal set of parameters.

Table. 1 Effect of controller parameters on system quality

Parameter	Rising Time	Over adjusting	Excessive time	Setting error
K_p	Decrease	Increase	Little change	Decrease
K_i	Decrease	Increase	Increase	Decrease
K_d	Little change	Decrease	Decrease	Unchange

B. *Fuzzy PID controller*

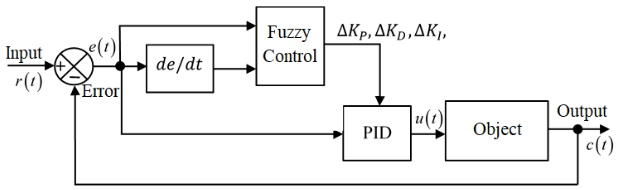


Fig. 3 Block diagram system control using Fuzzy PID

Block diagram system control using Fuzzy PID is shown in Fig. 3. Fuzzy PID is based on rules, so it is very stable. It consists of two inputs, the first input is the error of the system (the difference between the reference value and the actual value), the second one is the change of the error (the derivation of the error). Its three outputs are the parameters of the PID controller, which is used to control the speed of the DC motor. The precision of the PID controller and the flexibility of the fuzzy controll are both in the fuzzy PID controller. Comparison of the output of controllers is done on Matlab-Simulink, shown in Fig. 4 and Table. 2.

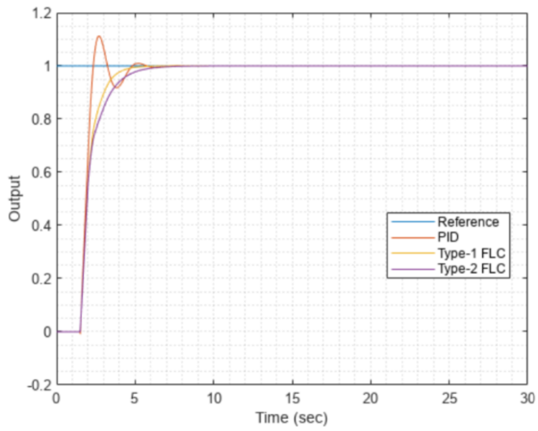


Fig. 4 Response of the system when using traditional PID controller, Sugeno fuzzy PID (type 1) and fuzzy PID using Karnik-Mendel algorithm (type 2) [17]

Table. 2 Comparison of some parameters of the controllers in Figure 3

Parameters / Type	Raise time	Over Adjusting	Transient time	Error
PID	0.62412	11.234	4.5583	1.04
FLC type 1	1.4267	0	4.1023	1.1522
FLC type 2	1.8662	0	5.129	1.282

C. *DC motor*

A DC motor uses direct current (DC) to produce mechanical force. The stator of a DC motor is usually one or more pairs of permanent magnets, or electromagnets. Its rotor has a winding wire and it is connected to a DC power source. Another important part is storage correction unit, it is responsible for changing the direction of current when the rotor turns continuously. Normally, for a DC motor, the rotational speed is proportional to the voltage applied to it, and the torque is proportional to the current. A DC motor's speed can be controlled by a variable supply voltage or by changing the strength of current in its field windings. In the system that we design, we use DC geared motor GA25 with some basic specifications:

- Voltage for motor operation: 3 - 12VDC
- Voltage for Encoder operation: 3.3VDC
- Gear ratio when passing through the reducer: 1:34
- Resolution: 44 pulses/rev.
- Motor diameter: 25mm.
- Shaft diameter: 4mm
- Torque: 1.88 kgf.cm

Fig. 5 DC geared motor GA25

D. *The other components*

1. Microcontroller STM32F103C8T6

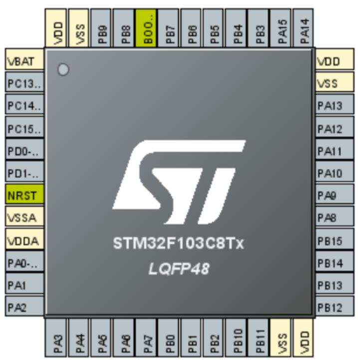


Fig. 6 Microcontroller STM32F103C8T6

STM32F103C8T6 [18] (in Fig. 6) is a microcontroller 32-bit, belonging to the F1 family of the chip family STM32. Its core is ARM COTEX M3 with a maximum speed of 72Mhz; Flash memory 64 kbytes and SRAM 20 kbytes; operating voltage from 2.0 to 3.6V; 4 Timers 16-bit and 2 watdog Timers… This series of high-density mid-performance microcontrollers is suitable for a wide range of applications such as motor control, medical and handheld devices, PC and gaming peripherals, GPS platforms, industrial applications…

2. Module wifi ESP8266

The ESP8266 [19] is a wifi transceiver module, which is commonly used for applications needing data connection and control via wifi. ESP8266 can use Arduino IDE to program directly. In addition, its built-in wifi 2.4GHz makes it simpler and easier to use. Some key parameters of the ESP8266 are 3.3V operating voltage; built-in antenna; 802.11 wireless connection standard;
2.4 GHz wifi supporting WPA/WPA2 sercurity;
110-460800 bps baudrate; 4 Mb memory size.

3. Motor control module L298

Using H-bridge chip - L298 [20] makes DC motor easy to control the speed and direction of rotation. In addition, it is also used when PWM control when needed. The H-bridge circuit of the L298 can operate at voltages from 5V to 35V.

5. Software

Nowadays, there are many software helping study algorithms and program for microcontrollers as well as design web servers. The authors have selected software that is easy to handle the requirements set out as STMCubeIDE (Genuine software with many tools to support in the process of writing programs for the microcontroller STM32F103C8T6); Mathlab Simulink (Simulate and research on Fuzzy-PID algorithms); Visual Studio Code (Write programs for web servers); Arduino (Write and load the ESP8266); Altium (Draw principle Circuit and PCB Circuit).

III. SYSTEM DESIGN

A. *Design Fuzzy PID controller*

Controller Requirements:

+ The system has high quality with the ability to follow the input signal.

+ The values of excessive time, setting error, over-shooting are small. In practice, the POT (Percent of OvershooT) of the system is usually less than 10%.

To design a fuzzy PID controller, at first, it is necessary to determine the physical value domains of the controller's input/output variables:

+ Determine the value domain of the error e:

The system uses a motor with a speed of 256 rpm, from that the speed control range for the motor is R=[0;256] rpm. We have:

$$e = R - C \tag{2}$$

$$e_{min} = R_{min} - C_{max} = 0 - 256 = -256$$

$$e_{max} = R_{max} - C_{min} = 256 - 0 = 256$$

The range of values of the error e[-256;256].

The range of error e depends on the range of values of the signal measured from the encoder during the sampling time T_s, so the range of the error values e is in the range [-30;30].

+ Determine the value domain of de/dt :

$$\frac{de}{dt} = \frac{e_0 - e_1}{T_s} \tag{3}$$

where e_0 is the current errror; e_1 is the previous error value; T_s is the sampling time (T_s = 100ms).

We choose the range of values of de/dt in the range [-100;100].

+ Determine the value domain of PID controller parameters:

We apply according to Mallesham-Rajani fuzzy regulation [15], Assuming that three parameters K_p, K_i, K_d are bounded:

$K_p^{min} \leq K_p \leq K_p^{max}$, $K_i^{min} \leq K_i \leq K_i^{max}$; $K_d^{min} \leq K_d \leq K_d^{max}$.

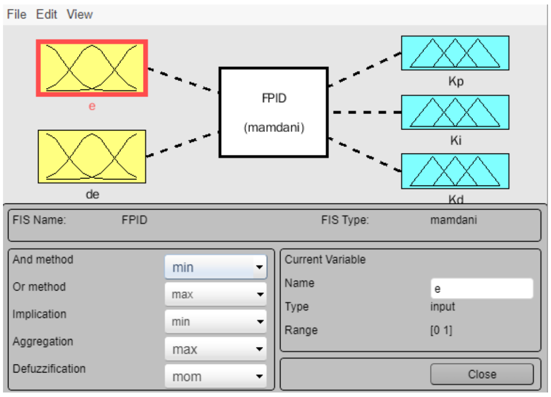


Fig. 7 Simulation of Fuzzy PID controller on Matlab-Simulink

After many experiments, we determined the intervals of these three parameters as follows:

$K_p = [0.005; 0.02]$; $K_i = [0.018; 0.03]$; $K_d = [0.0000003; 0.0003]$. These values are then normalized to the interval [0,1]. Mamdani model for fuzzy controller with MAX-MIN composition rule, average defuzzification method (MOM). It has two inputs (e; de/dt) and three outputs (K_p, K_i, K_d) simulated by Matlab software as shown in Fig. 7.

Here, each input and output of the fuzzy set consists of 5 membership functions corresponding to 5 linguistic variables:

Input: e= {NegBig, NegSmall, Zero, PosSmall, PosBig}

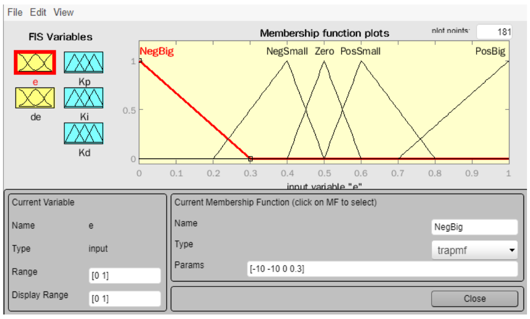
de/dt {DecFast, DecSlow, Maintain, IncSlow, Incfast}

Output: K_p, K_i, K_d = {VSmall, Small, Medium, Large, VLarge}.

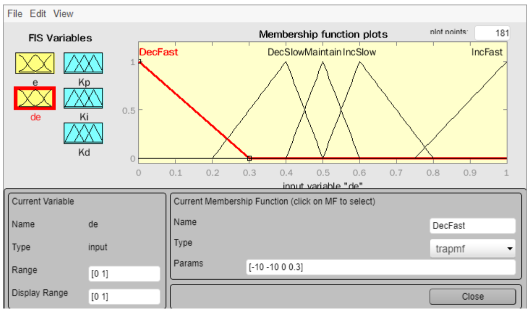
Determine the physical value domain of the input/output variables:

The determination of the range of values of physical and linguistic variables is based on guesswork and experience of designers. According to the above analysis, the group of implementations selected:

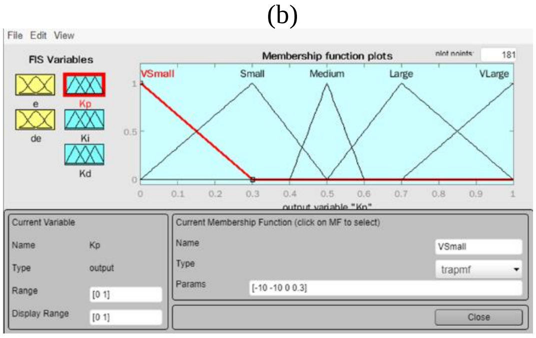
$e = [-30; 30]$; $de/dt = [-100; 100]$; $K_p = [0.005; 0.02]$; $K_i = [0.018; 0.03]$; $K_d = [0.0000003; 0.0003]$. The membership function of the selected input and output variables has a triangular shape as shown in Fig. 8. The fuzzy composition rule is designed according to Table. 4.



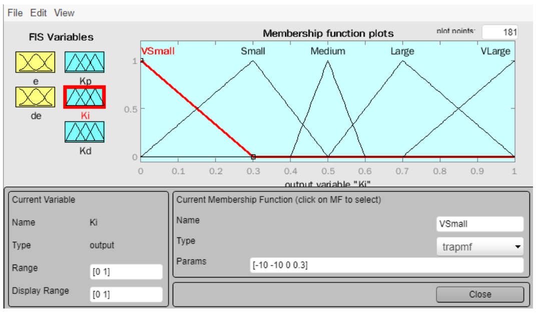
(a)



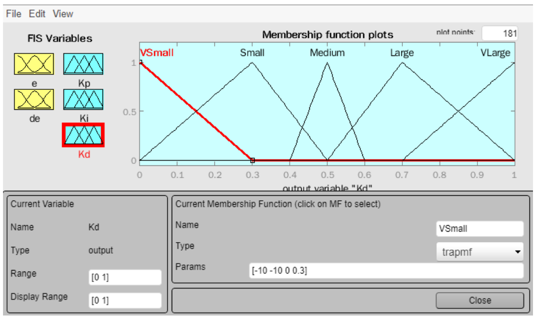
(b)



(c)



(d)



(e)

Fig. 8 Membership function of input and output: (a) – 'e', (b) - de/dt, (c) - K_p, (d) - K_i, (e) - K_d

Table. 4. Fuzzy composition rule

e \ de/dt	DecFast	DecSlow	Maintain	IncSlow	IncFast
NegBig	VLarge	VLarge	Large	Large	VLarge
NegSmall	Large	Medium	Small	Medium	Large
Zero	Small	VSmall	VSmall	Medium	Medium
PosSmall	Large	Medium	Medium	Large	Large
PosBig	VLarge	VLarge	Large	Large	VLarge

B. *Hardware design*

The hardware of the system is designed as shown in Fig. 1. Power supply for the circuit is a adapter with input AC from 100V - to 240V, frequency 50/60Hz, output DC 12V - 1A. Voltage 220 V_{ac} is put through the adapter to lower the voltage 12 Vdc for the motor.

C. *Web server design*

When any web Client (such as Web Browser) accesses, web server will base on the requested accessing information to process, and then respond to the requests.

The system uses HTTP protocol to exchange data between Client and Server based on TCP/IP, uses three languages such as HTML, Javascript and CSS to build and develop the web. It includes the following steps:

Step 1: Structure the content of the web page such as specifying paragraphs, titles, data tables, and embedding real-time graphs in HTML.

Step 2: Add interactive functions to send requests to receive data to the web and functions to receive data to plot real-time graphs. Use the Javascript language with <script> tags to embed programs in HTML.

Step 3: Handle the interface to make the web page more beautiful. Use CSS to control the color of the text, the font, the font size, the background image, or the background color. Use a custom graphic <Style> tag for each object to embed in HTML.

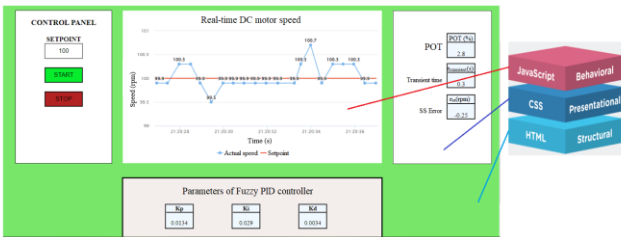


Fig.9 Web server design

IV. RESULTS AND DISCUSSION

Fig. 10 is the hardware that we design. Fig. 11 is the control interface for monitoring and controlling the motor via the web at 30 rpm. Here, the quality of the system is evaluated through three quality criteria: overshooting, transient time, and steady-state error. The control system has the following characteristics:

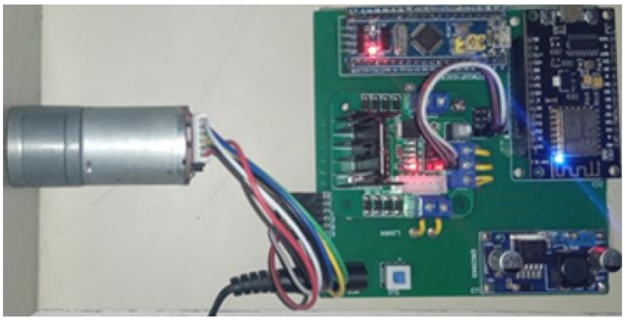


Fig 10 Hardware of system

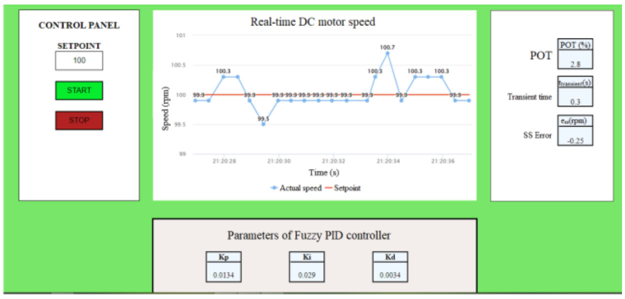


Fig.11 Motor control at speed 30 rpm

+ Control and stabilize the speed of the DC motor, the transient time is relatively fast, the error and the overshooting are small.

+ Control and monitoring interface via web server: data is updated continuously over time.

As shown in Fig. 12, there is difference at the output of DC motor for three cases such as not using a controller, using a traditional PID controller and using a fuzzy PID controller. We find that, when the system uses fuzzy controller, the system has faster speed and smaller error. At 50 rpm, the system has zero overshoot.

Table. 5 is the system performance parameters (POT, transient time, and steady-state error) at different DC motor speed levels. Changing motor speed can be done flexibly via web. We see that the above parameters are within the allowable range for a control system.

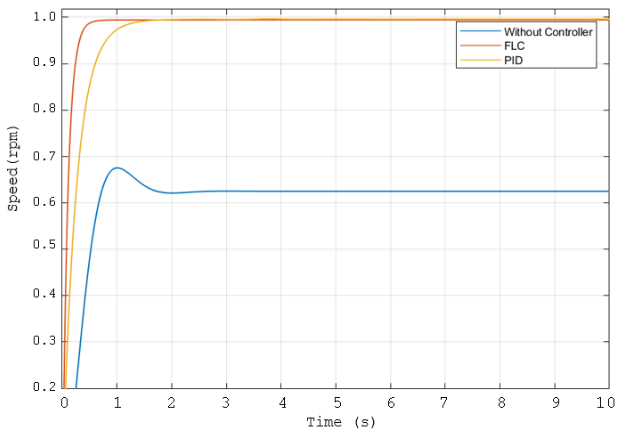


Fig. 12. Output of DC motor for three cases such as not using a controller, using a traditional PID controller and using a fuzzy PID controller at speed 50 rpm.

Table. 5 System quality parameters at speed levels

Parameters / Speed (rpm)	POT (%)	Transient time (s)	Steady-state error (%)
30	2.3	2.1	-0.6
50	0	0.6	-0.03
100	1.8	0.9	-0.25
120	0.6	0.5	0.01
160	0.5	0.8	0

V. CONCLUSION

The system uses a fuzzy PID controller to monitor the DC motor speed. The hardware with the Microcontroller STM32F103C8T6 process the measurement data of motor speed from the sensor and transmit it to the control center. The system can control the motor speed in real time via web server, measure, plot and monitor some parameters to evaluate the quality of the system.

The system is designed to work stably, and satisfy the criterias. The quality of the system is improved compared to the traditional PID controller. In order to improve the quality of the system, specifically with the object such as DC motor which has various speed in this paper, we can increase the resolution of the encoder to minimize measurement errors, thereby shorten the sampling time, increase the speed of the system. Choosing a motor whose speed matches the encoder resolution is necessary. In addition, increasing the number of linguistic variables and their membership functions will also increase the quality of the fuzzy PID controller.

ACKNOWLEDGMENT

Nghiên cứu này được tài trợ bởi Học viện Công nghệ Bưu chính Viễn thông có mã số 06-HV-2023-ĐT1.

REFERENCE

[1] Kang C-G, Origin of stability analysis: "on governors" [historical perspectives]. IEEE Control Syst Mag 36(5):77–88 2, 2016.

[2] Medaglia JD, Clarifying cognitive control and the controllable connectome. Wiley Interdiscip Rev Cognit Sci 10(1):1471 3, 2019.

[3] Åström KJ, Kumar PR, Control: a perspective. Automatica 50(1):3–43 4, 2014.

[4] Bennett S, The past of PID controllers. Ann Rev Control 25:43–53, 2000.

[5] Bennett S, Development of the PID controller. IEEE Control Syst Mag 13(6):58–62, 1993.

[6] Fong-Chwee T, Sirisena HR, Self-tuning PID controllers for dead time processes. IEEE Trans Ind Electr 35(1):119–125, 1988.

[7] Gaddam Mallesham, Akula Rajani, Automatic tuning of PID controller using fuzzy logic, 8th International Conference on Development and Application systems, 120-127, 2006.

[8] Kristiansson B, Lennartson B, Robust and optimal tuning of PI and PID controllers. IEE Proc Contr Theory Appl 149(1):17–25, 2002.

[9] Kaya Y, Yamamura S, A self-adaptive system with a variable-parameter PID controller. Trans Am Instit Electr Eng Part II Appl Ind 80(6):378–386, 1962.

[10] Sio KC, Lee CK, Stability of fuzzy PID controllers. IEEE Trans Syst Man Cybern Part A Syst Humans 28(4):490–495, 1998.

[11] Zhao Z-Y, Tomizuka M, Isaka S, Fuzzy gain scheduling of PID controllers. IEEE Trans Syst Man Cybern 23(5):1392–1398, 1993.

[12] Flores-Moran E, Yanez-Pazmino W and Barzola-Monteses J, Genetic algorithm and fuzzy self-tuning PID for DC motor position controllers (19th International Carpathian Control Conference): 162-168, 2018.

[13] Vincent Hardion, Darren Paul Spruce, Antonio Milan Otero, Julio Lidon-Simon, Mirjam Lindberg, Andreas Persson, MAXIV Laboratory, Lund, Sweden, The Internet of things and Control system. Proceedings of ICALEPCS2013, San Francisco, CA, USA, 974-977, 2013.

[14] N. Rajendran, Rupinder Singh, Manu Raj Moudgil, Anil V. Turukmane, M. Umadevi, K.B. Glory, Secured control systems through integrated IoT devices and control systems. Measurement: Sensors, Volume 24, December 2022, 100487, 2002.

[15] Aashirwad N. Sahare, Pranali A. Behare, Nikhil M. Dhote, Nirmal P. Shende, Ajinkya R. Kothe, Tushar G. Birole, Trupti S. Gajbhiye, Speed Controlling and Monitoring of DC Motor by using IOT. International Journal of Trend in Research and Development, Volume 7(4), ISSN: 2394-9333: 128-130, 2020.

[16] https://www.picuino.com/en/control-ziegler-nichols.html

[17] D. Wu and J. M. Mendel, Enhanced Karnik-Mendel Algorithms for Interval Type-2 Fuzzy Sets and Systems. NAFIPS 2007 - 2007 Annual Meeting of the North American Fuzzy Information Processing Society, San Diego, CA, USA, pp. 184-189, doi: 10.1109/NAFIPS.2007.383834, 2007.

[18] https://www.st.com/en/microcontrollers-microprocessors/stm32f103c8.html

[19] https://www.espressif.com/en/products/socs/esp8266

[20] https://www.alldatasheet.com/view.jsp?Searchword=L298&gclid=Cj0KCQjwrMKmBhCJARIsAHuEAPQrblEe9lJGHFN_1HBkyNXamXRLiAnd5HhXo6QYBXeeGn80xkj3gdgaAgFSEALw_wcB

GIÁM SÁT TỐC ĐỘ ĐỘNG CƠ ĐIỆN MỘT CHIỀU SỬ DỤNG BỘ ĐIỀU KHIỂN PID MỜ QUA WEB SERVER

Tóm tắt: Việc sử dụng bộ điều khiển PI, PD, PID để điều khiển động cơ có tốc độ thay đổi khó đáp ứng được yêu cầu về tính ổn định của hệ thống. Vì vậy, kết hợp thêm điều khiển mờ (Fuzzy) để điều chỉnh các tham số PID là một hướng đi mới để các hệ thống điều khiển tự động cải thiện chất lượng. Trong bài báo này, chúng tôi đề xuất một hệ thống sử dụng bộ điều khiển PID mờ, vi điều khiển STM32F103C8T6, module wifi ESP8266 để giám sát tốc độ động cơ một chiều và một số tham số đánh giá chất lượng của hệ thống qua web server. Mô phỏng hệ thống trên Matlab & Simulink xác nhận hiệu quả của hệ thống này.

Từ khóa: PID, PID mờ; động cơ một chiều, web server.

Vu Anh Dao received the Diploma of Cybernetics Engineer, Automatic Control and Measurement Master from Hanoi University of Science and Technology, Vietnam in 1999 and 2001, respectively. She has been studying as a PhD student at the School of Electronics and Telecommunications (SET), Hanoi University of Science and Technology (HUST), Vietnam since 2017, and is a lecturer in the Faculty of Electronics Engineering at the Posts and Telecommunications Institute of Technology (PTIT). Her main research

interests are Cybernetics, electronics design, all-optical signal processing, optical high-speed and chaos-based digital communications.

Bui Thi Dan received her Master's degree in Electronics and Telecommunications from Hanoi National University, Vietnam in 2003. She is a lecturer in the Department of Electronic Engineering at the Academy of Posts and Telecommunications. Technology (PTIT). Her main research interests are Telecommunications systems, electronic design, digital communication.