ตัวควบคุมฟัซซีลอจิกสำหรับระบบเซอร์โวตำแหน่งไฮดรอลิกไฟฟ้า

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บทคัดย่อ

เนื่องจากตัวควบคุมพีไอดีมีความอ่อนไหวต่อการเปลี่ยนแปลงค่าของตัวแปรในระบบเซอร์โวตำแหน่งไฮดรอลิกไฟฟ้า โดยเฉพาะอย่างยิ่งเมื่อภาระมีการเปลี่ยนแปลง ส่วนตัวควบคุมฟัซซีไม่ต้องการข้อมูลที่แม่นยำเกี่ยวกับตัวแปรของระบบที่ต้องการควบคุม บทความนี้นำเสนอการใช้ตัวควบคุมฟัซซีควบคุมระบบเซอร์โวตำแหน่งไฮดรอลิกไฟฟ้า โดยระบบที่ใช้ในการศึกษาครั้งนี้ประกอบด้วย กระบอกสูบ เซอร์โววาล์ว ชุดต้นกำลัง ภาระ โพเทนชิโอมิเตอร์เชิงเส้น ชุดขยายสัญญาณ และชุดเชื่อมต่อและเก็บรวบรวมข้อมูล ตัวควบคุมแบบฟัซซีถูกออกแบบบนฐานความรู้ของผู้เชี่ยวชาญ โดยอินพุตของฟัซซีจะประกอบด้วยความผิดพลาด (e) และการเปลี่ยนแปลงความผิดพลาดของตำแหน่ง (Δe) ส่วนเอาต์พุตของ ฟัซซีจะจ่ายแรงดันไฟฟ้าตามที่ต้องการให้กับชุดขยายสัญญาณของระบบเซอร์โวไฮดรอลิกไฟฟ้า ตัวควบคุมพีไอดีจะถูกนำมาเปรียบเทียบกับตัวควบคุมฟัซซี จากการทดลองพบว่าตัวควบคุมฟัซซีให้ผลตอบสนองดีกว่าตัวควบคุม พีไอดี ภายใต้เงื่อนไขที่มีภาระและไม่มีภาระ

คำสำคัญ : ตัวควบคุมพีไอดี, ตัวควบคุมฟัซซี, ระบบเซอร์โวตำแหน่งไฮดรอลิกไฟฟ้า

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A Fuzzy Logic Controller of Electro-Hydraulic Position Servo System

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Abstract

Since classical PID controllers are sensitive to variations in the electro-hydraulic position servo system (EHPSS) parameter, especially, when the load changes. Fuzzy Logic Controllers do not need precise information about the system variables in order to be effective. A Fuzzy Logic Controller (FLC) for the EHPSS is proposed in this paper. The EHPSS in this study consists of cylinder, servo valve (linear motor type), power unit, load, linear potentiometer, amplifier card, and DAQ card. A FLC is designed based on the expert knowledge. The fuzzy inputs are an error (e) and a change of position error (Δe). The fuzzy output is the required voltage that sent to the amplifier of EHPSS. The classical PID controller is implemented for comparing with FLC. The results show that a FLC has superior performance compared to a PID controller, under unloaded and loaded operating conditions.

Keywords: PID controller, fuzzy logic controller, electro-hydraulic position servo system

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1. Introduction

The application of hydraulic actuation to heavy duty equipment reflects the ability of the hydraulic circuit to transmit larger forces and to be easily controlled. It has many distinct advantages such as the fast response speed, very high system stiffness, and a higher force to weight ratio [1],[2]. The electro-hydraulic servo system, among others, is perhaps the most important system for position servo applications because it takes the advantages of both the large output power of traditional hydraulic systems and the rapid response of electric systems. Typical applications of electro-hydraulic position servo systems (EHPSS) include injection molding machines, different kinds of machine tools and construction machinery, etc. However, there are also many challenges in the design of electro-hydraulic control system [1],[2],[3],[4]. For example, they are the highly nonlinear phenomena such as fluid compressibility, the flow/pressure relationship and deadband due to the internal leakage and hysteresis, and the many uncertainties of hydraulic systems due to linearization. Therefore, it seems to be quite difficult to perform a high precision servo control by using linear control method.

Classical PID controller is the most popular control tool in many industrial applications because they can improve both the transient response and steady state error of the system at the same time. Moreover, it has simple architecture and conceivable physical intuition of its parameter [5],[6]. Traditionally, the parameters of a classical PID controller, i.e. K_P, K_I, and K_D, are usually fixed during operation. Consequently, such a controller is inefficient for control a system while the system is disturbed by unknown facts, or the surrounding environment of the system is changed.

Fuzzy control is robust to the system with variation of system dynamics and the system of model free or the system which precise information is not required. It has been successfully used in the complex ill-defined process with better performance than that of a PID controller. Another important advance of fuzzy controller is a short rise time and a small overshoot [2],[3],[7].

In this paper, a FLC is proposed for controlling an EHPSS. The remainder of this paper is organized as follows: section 2 presents the dynamic model of the EHPSS, section 3 present the control systems, section 4 presents the description of experiment equipment, section 5 discusses the experimental results, and section 6 summarizes the contributions of the works and outline future planes.

2. Dynamic model of electro-hydraulic position servo systems

The block diagram of the hydraulic position servo system [8] is shown in Fig.1. The valve displacement and the flow rate are governed by the orifice law that is

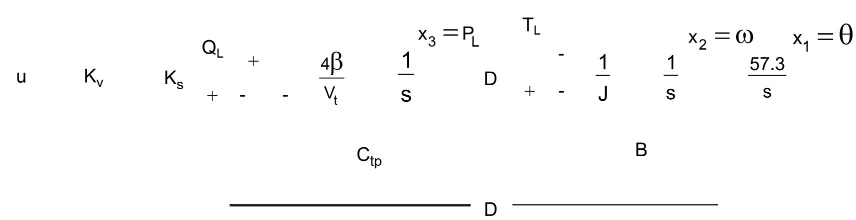

Figure 1 The block diagrams of the EHPSS.

$$Q_L = X_v K_j \sqrt{P_s - \mathrm{sgn}(X_v) P_L} = X_v K_s \qquad (1)$$

Where K_j is a constant depended on the specific hydraulic component. P_s and P_L are the supply pressure and the load pressure. Hence, the valve flow gain K_s will be depended on the working conditions. The volume and continuity expressions can be combined to yield

$$Q_L = D\omega + C_{tp} P_L + \frac{4\beta}{V_t}\dot{P}_L \qquad (2)$$

which is the usual form of the continuity equation. D is volumetric displacement. C_{tp} is the total leakage coefficient. β is the bulk modulus of the oil and V_t is the total volume of the oil. ω is the velocity of the hydraulic cylinder. The resulting torque equation is

$$T = DP_L = J\dot{\omega} + B\omega + T_L \qquad (3)$$

where J is the total inertia coefficient of the hydraulic cylinder and B is the viscous damping constant. The spring load T_L will vary depended on the Hook's law, that is, $T_L = K_H \theta$ where K_H is the Hook's constant. The hydraulic cylinder position θ is obtained by

$$\theta = \frac{54.3\omega}{s} \qquad (4)$$

where the constant 57.3 cm/rad is the transforming gain from radius to centimeters. The variables of position θ, velocity ω and load pressure P_L, are all measurable.

Therefore, the electro hydraulic position servo system call be described as

$$\dot{x}_1 = -a_{11}x_1 - a_{12}x_2 - a_{13}x_3 - f_1 \qquad (5a)$$
$$\dot{x}_2 = -a_{21}x_1 - a_{22}x_2 - a_{23}x_3 - f_2 \qquad (5b)$$
$$\dot{x}_3 = -a_{31}x_1 - a_{32}x_2 - a_{33}x_3 - f_3 + bu \qquad (5c)$$
$$y = c_1x_1 + c_2x_2 + c_3x_3 \qquad (5d)$$

where y = θ means the hydraulic position and

$$a_{11} = a_{13} = a_{23} = a_{31} = f_1 = f_3 = 0, a_{12} = 57.3,$$
$$a_{21} = \frac{B}{J}, a_{22} = \frac{D}{J}, a_{32} = \frac{4\beta}{V_t}D, a_{33} = \frac{4\beta}{V_t}C_{tp}$$
$$b = \frac{4\beta}{V_t}K_v K, \text{ and } f_2 = \frac{1}{J}T_{Ls}$$

Using the forward difference transformation, that is

$$\dot{x} = \frac{x(k+1) - x(k)}{T}$$

where T is the sampling time period, one has the discretized system equations as

$$x_1(k+1) = x_1(k) - Ta_{11}x_1(k) - Ta_{12}x_2(k) - Ta_{13}x_3(k) - Tf_1(k) \qquad (6a)$$
$$x_2(k+1) = x_2(k) - Ta_{21}x_1(k) - Ta_{22}x_2(k) - Ta_{23}x_3(k) - Tf_2(k) \qquad (6b)$$
$$x_3(k+1) = x_3(k) - Ta_{31}x_1(k) - Ta_{32}x_2(k) - Ta_{33}x_3(k) - Tf_3(k) + Tbu(k) \qquad (6c)$$
$$y(k) = c_1x_1(k) + c_2x_2(k) + c_3x_3(k) \qquad (6d)$$

3. Control Systems

There are various types of control system logic used in classical control, modern control and intelligent control systems, each having been studied and implemented in many industrial applications. Every control system method has its advantages and disadvantages. Therefore, the trend is to implement hybrid systems consisting of more than one type of control technique. This section describes the logic of classic PID control and fuzzy control.

3.1 PID Controls

The PID control method has been widely used in industry during last several decades because of its simplicity. The implementation of PID control logic, as shown in Eq. (6), requires finding suitable values for the gain parameters K_P, K_I, and K_D. To tune these parameters, the model is linearized around different equilibrium points,

$$u(k) = K_P e(k) + K_I \sum_{i=0}^{k} e(i) + K_D\left[e(k) - e(k-1)\right] \quad (7)$$

where e(k) is the error signal. However, the PID method is not suitable for controlling a system with a large amount of lag, parameter variations, and uncertainty in the model. Thus, PID control logic cannot accurately control position in a hydraulic system.

3.2 Fuzzy Controls

FLC has the advantage that it does not require an accurate mathematical model of the process. It uses a set of artificial rules in a decision-making table and calculates an output based on the table [1],[2],[3]. Fig.2 shows a fuzzy control of the EHPSS. Input variables go through the fuzzification interface and are converted to linguistic variables. Then, a database and rule base holding the decision-making logic are used to infer the fuzzy output. Finally, a defuzzification method converts the fuzzy output into a signal to be sent out.

When used in a control system, FLC is robust since it provides a fast rise time and a small amount of overshoot [2],[3]. The control parameters and set of terms that describe each linguistic variable must be determined when designing a FLC. Obviously, the position in the electro-hydraulic is the parameter to be controlled in the system. A two-dimension structure will be used to produce fast calculations. The two input linguistic variables are the error of the position (e) and the error change of the position (Δe). The output is the voltage signal to control the amplifier and servo valve. Thus, the FLC has two antecedences and one consequence.

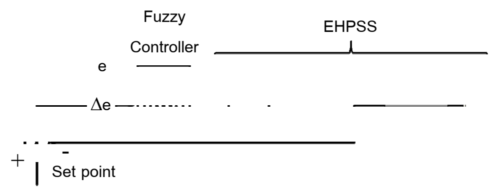

Figure 2 A fuzzy controls of the EHPSS.

First, the two input variables must be defined in terms of linguistics. The error in position is expressed by a number in the interval from -10 to 10. There are five linguistic terms of the error in position: negative big (NB), negative (N), zero (Z), positive (P), and positive big (PB). Similarly, the fuzzy set of the error change of the position is presented as {NB, N, Z, P, PB} over the interval from -10 to 10. Finally, the fuzzy set of the output signal is presented as {NB, N, Z, P, PB} over the interval from -10 to 10.

The knowledge base for a FLC consists of a rule base and membership functions. It is reasonable to present these linguistic terms by triangular-shape membership functions, as shown in Fig.3. An expert's experience and knowledge method is used to build a rule base [6]. The rule base consists of a set of linguistic IF-THEN rules containing two antecedences and one consequence, as expressed in the following form:

$$R_{i,j,k} : \text{IF } e = A_i \text{ and } \Delta e = B_j \text{ THEN } u = C_k,$$

where $1 \leq i \leq 5$, $1 \leq j \leq 5$, and $1 \leq k \leq 5$. The total number of IF-THEN rules is 25 and is represented in matrix form, called a fuzzy rule matrix, as shown in Table1.

The decision-making output can be obtained using a max-min fuzzy inference where the crisp output is calculated by the center of gravity (COG) method.

A set of fuzzy rules is shown in the Table1. The fuzzy rules in the center of the table are related to the steady state behavior of the process. When both the position error (e) and the change of position error (Δe) are negative, that is over set point position. In response the control action should be negative value such that it will reduce the position error. While the "Δe" is positive and the "e" is negative, the piston is moving toward, thus the control action should be low enough to slow down the approach to the set point. Other fuzzy rules are obtained in Table1 consider from Fig.2.

Since the dynamics of cylinder is not symmetric, due to the difference in the effective area of the rod side and the head side of the piston. The designed fuzzy set of the FLC accounts for this asymmetry as well.

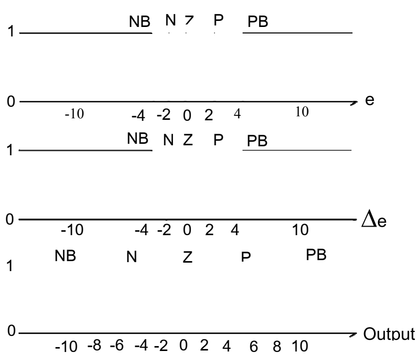

Figure 3 Fuzzy sets of a FLC.

Table 1 Fuzzy rules of a FLC

e \ Δe	NB	N	Z	P	PB
NB	NB	NB	N	N	Z
N	NB	N	N	Z	P
Z	N	N	Z	P	P
P	N	Z	P	P	PB
PB	Z	P	P	PB	PB

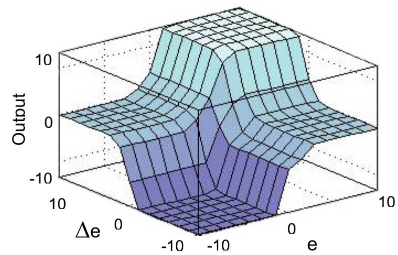

Figure 4 Input-output mapping of a FLC.

With two inputs and one output the input-output mapping is a surface. Fig.4 is a mesh plot of a relationship between e and Δe on the input side, and controller output side.

4. Description of Experiment Equipment

The specifications of an EHPSS are depicted in Fig. 5 and Table2 respectively. Fig.5 shows a diagram of the tested system. The position control of an EHPSS procedure is described as follows: upon the intended initial and ending position of the piston (stroke) are given, the computer receives the feedback signal through DAQ card (A/D) from linear potentiometer, realizes various control algorithm and transmits a control signal through DAQ card (D/A) and amplifier card to servo valve. The piston displacement of cylinder is proportional to the input signal.

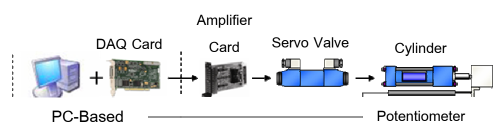

Figure 5 PC-Based position controls of the EHPSS.

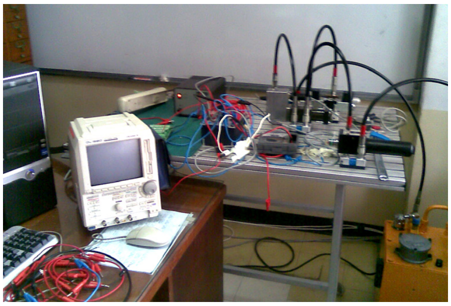

Figure 6 Experiment set-up.

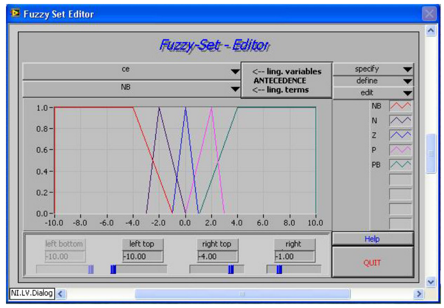

Figure 7 Fuzzy sets of a FLC developed using LabVIEW program.

Table 2 Specifications of the EHPSS

Elements	Descriptions
Cylinder	piston diameter 16 mm, piston rod diameter 10 mm, stroke 200 mm
Servo valve (linear motor type)	directly actuated spool valve, grade of filtration 10 μm, nominal flow rate 1.5l/min (at Δp_N = 5 bar/control edge), leakage oil flow < 0.01 l/min (at 60 bar), nominal current 680 mA, resolution < 1 mA, setting time of signal jump 0…100% = 60 ms, repetition accuracy < 1%
Pump (supply pressure)	60 bar
Load	5 kg.
Linear potentiometer	output voltage 0…10V, measuring stroke 200 mm, linearity tolerance 0.5%
Amplifier card	set point values ± 10 VDC, solenoid outputs (PWM signal) 24 V, dither frequency 200 Hz, max current 800 mA,
DAQ Card (NI 6221 PCI)	analog input resolutions 16 bits (input range ±10V), output resolutions 16 bits (output range ±10V), Sampling period time = 100msec.
Operating systems & Program	Windows XP, and LabVIEW 8.2

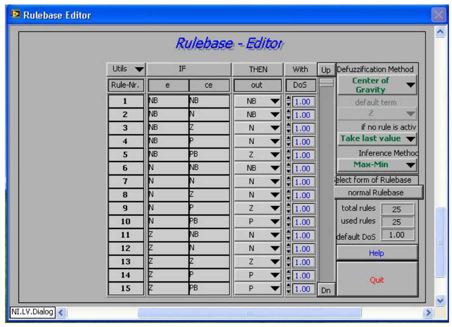

Figure 8 Fuzzy rules of a FLC developed using LabVIEW program.

5. The Experimental Results

The control algorithms described in section 3, were applied to the EHPSS shown in Fig.6 using LabVIEW by Nation Instruments as the development platform.

In our experiments we compare the performance of a PID controller to the proposed FLC. A testing of response of the system was performed using a unit step input. The position response of the EHPSS was operated for a required reference position under loaded (5kg.) and unloaded operating conditions (sampling period time in our experiments was 100 msec.). The PID control method was applied to a system with many difference positions of the EHPSS. The results from experiments find that the control parameters need to be adjusted to different values. Fig.9 and Fig.11 show the optimum dynamic response under unloaded and loaded operating conditions. Fig.10 and Fig.12 show the dynamic response of the system using a FLC under unloaded and loaded operating conditions respectively. The results show that a FLC has superior performance (shorter rise time) compared to a PID controller.

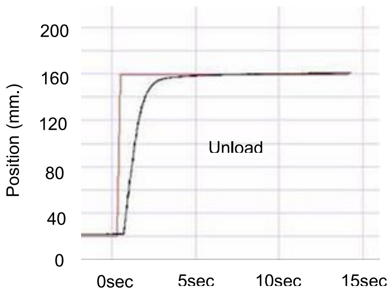

Figure 9 Output responses of a PID controller.

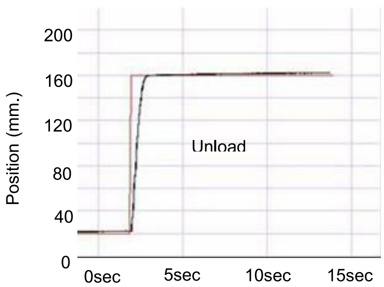

Figure 10 Output responses of a FLC.

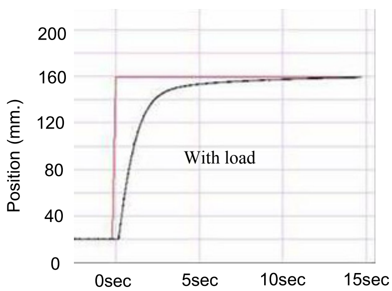

Figure 11 Output responses of a PID controller.

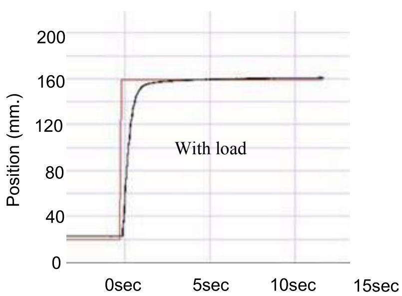

Figure 12 Output responses of a FLC.

6. Conclusions and future works

The design and implementation of a PC-based position control of the EHPSS using both FLC and PID have been presented in this papers, the experimental study reveals that using FLC obtained shorter settling time. The results can be achieved by tuning the fuzzy rules, membership functions, and universe of discourse of the output variable. The comparisons of experimental results of the both PID and FLC show that the FLC is able to perform better than the PID controller. The results indicated that even without knowing the detail of the control plants, we were able to construct a well performed FLC based on the expert knowledge. According to some researches [1],[2],[3], therefore, it can be concluded that a FLC is suited for the EHPSS.

As future, this research will be developed to teach and learn of teacher training in mechatronics engineering students at King Mongkut's University of North Bangkok (KMUTNB). Because the LabVIEW program combines the advantages of graphical programming and high quality user interface tools. The student can design and control the fundamental parameters of the controller topology through the user interface. Moreover, future research will be concentrated on the intelligence control system, such as hybrid fuzzy-genetic algorithm and neuro-fuzzy controller for EHPSS.

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