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FUZZY ALGORITHM FOR THE COMMAND OF THE POSITION FOR THE PISTON OF AN ELECTRO-HYDRAULIC SYSTEM

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ABSTRACT. This paper presents the way to create a fuzzy regulator used to command a fluid flow servo-valve with force reaction, this servo-valve being the execution element of an electro-hydraulic adaptation system which adjusts the position on one axel. Practically, beginning from a value of the reference (the position in which we wish to move the free extremity of the hydraulic cylinder’s piston’s cane), for example at half the distance the piston covers and at a value of the speed with which the piston moves at a certain moment, the paper goes through all the stages of fuzzy algorithm and a firm value of the command which the regulator produces in this case. The spread of the applications’ field of the numerical systems for adjustment and control of the technological processes is, obviously, sustained by the superior performances achieved by such systems, as is the case of the fuzzy system, comparing to the conventional analogical automated systems.

АЛГОРИТЪМ ЗА УПРАВЛЕНИЕ БУТАЛОТО НА ЕЛЕКТРОХИДРАВЛИЧНА СИСТЕМА

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РЕЗЮМЕ. Този доклад представя начин за създаване на регулатор за управление на серво-клапа за потока на флуида, като тази серво-клапа е изпълнителния елемент от електро-хидравлична система, която регулира позицията на една от осите. На практика, започвайки от дадена стойност (позицията, от които искаме да придвижим буталото на хидравличния цилиндър), например, на половината от разстоянието, покрито от буталото и скорост, с която буталото се движи в определен момент, докладът преминава през всички етапи на алгоритъма и стойността на командата, която дава регулатора в дадения случай. Широкото разпространение на приложение на числените системи за регулиране и управление на технологичните процеси очевидно се поддържа от характеристиките на тези системи, както е в случая на размитите системи, в сравнение с конвенционалните аналогови автоматизирани системи.

INTRODUCTION

In the last years, a significant increase of the number of various fuzzy applications has been noticed.

Applications of this type have extended upon different domains, such as: hi-tech filming devices (photo and recording cameras), washing machines, micro wave devices, and also upon the industrial control systems and the high performance medical instruments.

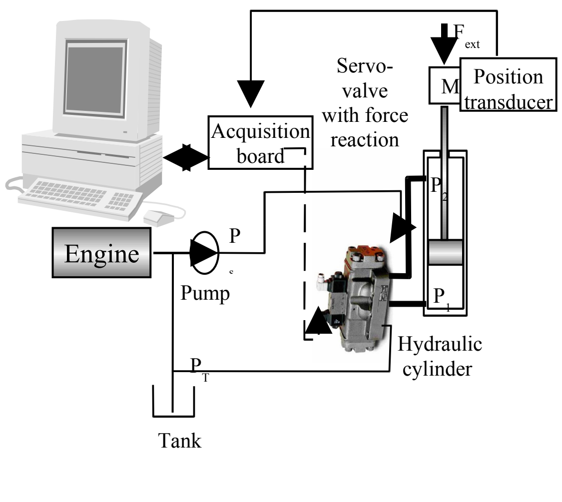


Fig.1. The functional scheme of the designed experimental system

The experimental model (fig. 1) we designed to observe the ways in which a fluid flow servo-valve with force reaction can be controlled, is a one axel positioning system.

The servo-valve we used is one of the 72 series, built by MOOG and is voltage controlled (-10 ÷ +10 Vcc), with 300Ω resistance at the command coil.

The hydraulic cylinder with double effect has a distance of 250mm for the piston to cover and piston’s diameter of 60mm. The position transducer WE used is a resistive transducer (multiple shift potentiometer), and consists of a system which converts the translation movement of the piston into a rotation movement which is transferred directly to the potentiometer.

The control of the process is made with the help of the computer through an acquisition and control board which is based on a ATMEL 89C52 microcontroller, and which communicates with the calculus system though the serial port. The acquisition system has:

– an analogical input to read the potentiometer;
– an analogical output for the numerical-analogical converter which controls the servo-valve;
– a serial communication channel for the connection with the computer.

DESIGN OF THE FUZZY REGULATOR

CHOOSING THE LINGUISTIC VARIABLES AND TERMS

To adjust the position of the cylinder's piston, we defined three linguistic variables, associated to the input quantities (position error and movement speed of the piston) and output quantities (command):

- position error – an input linguistic variable which varies between $[e_{min} \div e_{max}]$ mm;
- movement speed of piston – the second input linguistic variable which calculates as the ratio of the distance between two successive readings of the position transducer and the time between the two readings, with values in the interval $[v_{min} \div v_{max}]$ mm/s;
- command – output linguistic variable which varies between $[U_{min} \div U_{max}]$.

Observation: The variation domain of the output (command) is considered in unities of the numeric-analogical converter (NAC) MAX 536, used for the command of the servo-valve. This is a convertor on 12 bits with differential output (-2,5 ÷ +2,5)*, the domain in which the command of the fuzzy regulator varies is* (0 ÷ 4096)*. So:*

- *when we want a 0 command, the number of NAC must be 2048;*
- *when we want a* (-2,5 ÷ 0)V *command, the number of NAC unities must be between* (0 ÷ 2048) *;*
- *when we want a* (0 ÷ +2,5)V *command, the number of NAC unities must be between* (2048 ÷ 4096)*.*

It follows a vague representation of the position error for the variation domain $[e_{min} \div e_{max}]$ mm and of the movement speed of the piston for the $[v_{min} \div v_{max}]$ mm/s domain, through the affiliated functions and a vague representation of the command for the $[U_{min} \div U_{max}]$ domain.

The linguistic variables position error may be vaguely characterized through the following linguistic terms:

ε_{Mn} – high negative position error - with the affiliation function:

$$\mu_{\varepsilon Mn}=(e_{min}, e_{min}, e_{Mn}, e_{zen}) \quad (1)$$

ε_{mdn} – medium negative position error - with the affiliation function:

$$\mu_{\varepsilon mdn}=(e_{Mn}, e_{mdn}, 0) \quad (2)$$

ε_{ze} – zero position error - with the affiliation function:

$$\mu_{\varepsilon ze}=(e_{zen}, 0, e_{zep}) \quad (3)$$

ε_{mdp} – medium positive position error - with the affiliation function:

$$\mu_{\varepsilon mdp}=(0, e_{mdp}, e_{Mp}) \quad (4)$$

ε_{Mp} – high positive position error - with the affiliation function:

$$\mu_{\varepsilon Mp}=(e_{zep}, e_{Mp}, e_{max}, e_{max}) \quad (5)$$

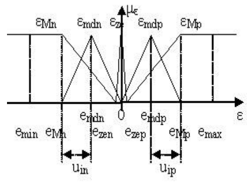
where e_{min}, e_{max}, e_{zen} AND e_{zep} are given as initial data, and other parameters are to be calculated for generality with the following relations:

$$u_{ip} = e_{max}/3;\ u_{in} = e_{min}/3;\ e_{min} = -250;\ e_{max} = 250;\ e_{Man} = 2^* u_{ip};$$
$$e_{mnd} = u_{in};\ e_{mdp} = u_{ip}; \quad (6)$$
$$e_{Map} = 2^* u_{ip};\ e_{zen} = -100;\ e_{zep} = 100;$$

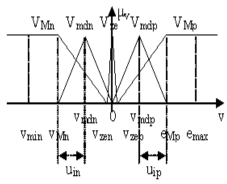
As is observed in fig. 2a and b, for the linguistic variables: position error and movement speed of the piston, the shapes of the affiliated functions afferent to the linguistic terms e_{Mn}, v_{Mn}, e_{Mp}, v_{Mp}, is like a trapeze, and for the linguistic terms e_{mdn}, v_{mdn}, e_{ze}, v_{ze}, e_{mdp} si v_{mdp} is triangular symmetric.

Linguistic variable speed of movement of the piston can be vaguely characterized through the following linguistic terms:

v_{Mn} – high negative speed with the affiliated trapeze function:



a)



b)

Fig.2. The shape of the affiliated functions for the linguistic variables: position error and speed of piston

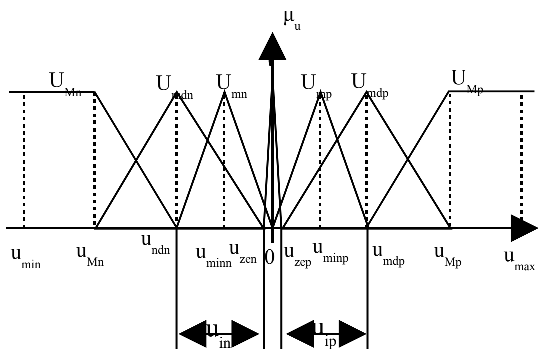


Fig.3. The shape of the affiliated functions for the linguistic variable command

$$\mu_{vMn} = (v_{min}, v_{min}, v_{Man}, v_{zen}) \quad (7)$$

v_{mdn} – medium negative speed with the affiliated triangular function:

$$\mu_{vmdn}= (v_{Man}, v_{mdn}, 0) \quad (8)$$

v_{ze} – zero speed with the affiliated triangular function:

$$\mu_{vze}= (v_{zen}, 0, v_{zep}) \quad (9)$$

v_{mdp} – zero speed with the affiliated triangular function:

$$\mu_{vmdp}= (0, v_{mdp}, v_{Map}) \quad (10)$$

v_{Mp} – the high positive speed with the affiliated trapeze function:

$$\mu_{vMp}= (v_{zep}, v_{Map}, v_{max}, v_{max}) \quad (11)$$

To represent vaguely the linguistic variable speed of movement for the piston, I adopted the following calculus relations:

$$u_{ip} = v_{max}/3;\ u_{in} = v_{min}/3;\ v_{min} = -100;\ v_{max} = 100;\ v_{Man} = 2^* u_{ip};\ v_{mnd} = u_{in};\ v_{mdp} = u_{ip};\ v_{Map} = 2^* u_{ip};\ v_{zen} = -40;\ v_{zep} = 40; \quad (12)$$

The linguistic variable command can be vaguely characterized through the following linguistic terms:

U_{M_n} – high negative command with the affiliated trapeze function:

$$\mu_{UM\text{-}n} = (u_{min}, u_{min}, u_{Man}, u_{mdn}) \quad (13)$$

$U_{md\text{-}n}$ – medium negative command with the affiliated triangular function:

$$\mu_{Umd\text{-}n} = (u_{Man}, u_{mdn}, u_{zen}) \quad (14)$$

$U_{m\text{-}n}$ – low negative command with the affiliated triangular function:

$$\mu_{Um\text{-}n} = (u_{mdn}, u_{minn}, 0) \quad (15)$$

U_0 – zero command with the affiliated triangular function:

$$\mu_{U0} = (u_{zen}, 0, u_{zep}) \quad (16)$$

$U_{m\text{-}p}$ – low positive command with the affiliated triangular function:

$$\mu_{Um\text{-}p} = (0, u_{minp}, u_{mdp}) \quad (17)$$

$U_{md\text{-}p}$ – medium positive command with the affiliated triangular function:

$$\mu_{Umd\text{-}p} = (u_{zep}, u_{mdp}, u_{Map})$$

$U_{M\text{-}p}$ – high positive command with the affiliated trapeze function:

$$\mu_{UM\text{-}p} = (u_{mdp}, u_{Map}, u_{max}, u_{max}) \quad (18)$$

To represent vaguely the linguistic variable command, I adopted the following calculus relations:

$$u_{min}= 0;\ u_{max}= 4096;\ u_{zen}= 2000;\ u_{zep}= 2096;\ u_{in}= (u_{zen} - u_{min})/3;\ u_{minp}=2048+ (u_{mdp} - 2048)/2;\ u_{minn}= 2048- (u_{mdp} - 2048)/2;\ u_{mdp}=2048+ u_{zep} + u_{in};\ u_{mdn}=2048- u_{zen} - u_{in};\ u_{Mp}= 2048+u_{zep} + 2^*u_{in};\ u_{Mn}= 2048-u_{zep} + 2^*u_{in}; \quad (19)$$

The shape of the affiliated functions afferent to the linguistic terms $U_{M\text{-}n}$ si $U_{M\text{-}p}$ is a trapeze, while the one of the $U_{md\text{-}n}$, $U_{m\text{-}n}$, $U_{m\text{-}p}$, $U_{md\text{-}p}$ and U_0 are triangular symmetric as seen in fig. 3.

When I built the base of rules, I took into account:

- the number of sequences of the base of rules (not to mistake the number of sequences with the number of rules) is equal to the number of linguistic terms of the input linguistic variable position error;
- we continue to consider that the position reference is situated at the half of the piston distance to cover;
- we consider the high positive position error when the piston is retired into the cylinder;
- we consider the zero position error when the piston is close to the half of the distance;
- we consider the high negative position error when the piston almost got out the cylinder;
- the speed is positive when the piston moves to right (forward move) and negative when it moves to left (withdraw move);
- also, the command can be low, medium and high in a positive way when the piston goes forward, so that its speed to become positive, low, medium and high in a negative way when the piston retreats, and zero command when the piston doesn't move.

Taking into account the considerations above and all the situations which may appear in the regulated process, the whole resulted base of rules is:

R1: IF (ε_{Mn} AND v_{Mn}) THEN U_{M_n};
R2: IF (ε_{Mn} AND v_{mdn}) THEN U_{M_n};
R3: IF (ε_{Mn} AND v_{ze}) THEN U_{M_n};
R4: IF (ε_{Mn} AND v_{mdp}) THEN U_{M_n};
R5: IF (ε_{Mn} AND v_{Mp}) THEN U_{M_n};
R6: IF (ε_{mdn} AND v_{Mn}) THEN U_{md_n};
R7: IF (ε_{mdn} AND v_{mdn}) THEN U_{md_n};
R8: IF (ε_{mdn} AND v_{ze}) THEN U_{md_n};
R9: IF (ε_{mdn} AND v_{mdp}) THEN U_{M_n};
R10: IF (ε_{mdn} AND v_{Mp}) THEN U_{M_n};
R11: IF (ε_{ze} AND v_{Mn}) THEN U_{m_n};
R12: IF (ε_{ze} AND v_{mdn}) THEN U_{m_n};
R13: IF (ε_{ze} AND v_{ze}) THEN U_0;
R14: IF (ε_{ze} AND v_{mdp}) THEN U_{m_p};
R15: IF (ε_{ze} AND v_{Mp}) THEN U_{md_p};
R16: IF (ε_{mdp} AND v_{Mn}) THEN U_{md_p};
R17: IF (ε_{mdp} AND v_{mdn}) THEN U_{md_p};
R18: IF (ε_{mdp} AND v_{ze}) THEN U_{md_p};
R19: IF (ε_{mdp} AND v_{mdp}) THEN U_{md_p};
R20: IF (ε_{mdp} AND v_{Mp}) THEN U_{m_p};
R21: IF (ε_{Mp} AND v_{Mn}) THEN U_{M_p};
R22: IF (ε_{Mp} AND v_{mdn}) THEN U_{M_p};
R23: IF (ε_{Mp} AND v_{ze}) THEN U_{M_p};
R24: IF (ε_{Mp} AND v_{mdp}) THEN U_{M_p};
R25: IF (ε_{Mp} AND v_{Mp}) THEN U_{M_p};

For another value of the reference, the basis of rules will have to be modified accordingly, in order for that a new sequence of the basis of rules to be evaluated function of the value. To reduce the complexity of this algorithm, we'll consider the reference at half the distance between min and max.

VAGUE INFERENCE. EVALUATION OF THE IF …THEN RULES

The vague inference is the algorithm after which the implications IF (premise) – THEN (conclusion), reunited in a base of rules, are evaluated. In the evaluation of the inference we can use the MAX – MIN, MAX – PROD or SUM-PROD compositions.

To understand the inference mechanism which is the base of a fuzzy regulator, we have the following case study: We consider that at a certain moment, the position error has the value 125 and the movement speed of the piston is 25 mm/s.

To determine the affiliation degrees of these firm quantities at the corresponding linguistic terms, we used the affiliated functions of triangular and trapeze type.

The afferent value of the affiliation degrees of firm quantities ε = 125 to defined linguistic terms are according to relation (17).

$$\varepsilon_0 = \{0, 0, 0, 0.5, 0.37\} \quad (20)$$

Proceeding in the same way for calculation of affiliation degrees of firm quantities v=25 of piston movement speed, this are according to relation (18).

$$v_0 = \{0 , 0 , 0.37, 0.75, 0 \} \qquad (21)$$

In any τ moment, fuzzy algorithm activate rules from BRF (as parallel process). The output of each fuzzy rule is a fuzzy value, which result from basic operations in fuzzy logic. Therefore each rule from BRF represent a logic expression realized with conjunction AND operator.

Thereafter we apply AND operation of fuzzy sets, after that on output we obtain a punctual minimum of affiliation functions from entire definition domain of output variables.
So, for a rule from BRF with form:

R1: IF (ε_{Mn} AND v_{Mn}) THEN U_{M_n}

we have:

$$\omega U_{M\_n} = MIN (0, 0) = 0; \qquad (22)$$

where:
ωU_{M_n} – is activation scalar value of fuzzy set U_{M_n}.
So this is a rule which won't use because the activation scalar value of fuzzy set U_{M_n} of output variable is zero.

Follow up we retain only the useful rules for the supposed numeric case which are 4.

R18: IF (ε_{mdp} AND v_{ze}) THEN U_{md_p}

For this rule the activation scalar value is: ω_{Umd_p} = MIN (0.5 , 0.37) = 0.37;

R19: IF (ε_{mdp} AND v_{mdp}) THEN U_{md_p}

For this rule the activation scalar value is: ω_{Umd_p} = MIN (0.5 , 0.75) = 0.5;

R23: IF (ε_{Mp} AND v_{ze}) THEN U_{M_p}

For this rule the activation scalar value is: ω_{UM_p} = MIN (0.37 , 0.37) = 0.37;

R24: IF (ε_{Mp} AND v_{mdp}) THEN U_{M_p}

For this rule the activation scalar value is: ω_{UM_p} = MIN (0.5 , 0.75) = 0.5 .

We remark that in inference process the rules can have like result the same output fuzzy set, in generally activated by the different ω_i coefficients. This is the case of rules R18 and R19 from this example which have the output fuzzy set the command $\mathbf{U_{md\_p}}$, respectively R23 and R24 which have the output fuzzy set the command $\mathbf{U_{M\_p}}$. Thereafter, the inference operation is analyzed on the entire level of BRF through a composition technique of the elementary inferences results (from each i rule activated).

In this case we use the composition method noted as MAX, according whom the rules which have the same output fuzzy set, this (output fuzzy set) is activated (ponderate) with the maximum value of ω_i coefficient.

Therefore the rules R18 and R19 the output fuzzy set U_{md_p} will be ponderated with $\omega\, U_{md\_p}$ coefficient calculated in this way:

$$\omega U_{md\_p} = MAX (\omega_{18} , \omega_{19}) = $$
$$= MAX (0.37 , 0.5) = 0.5 \qquad (23)$$

respectively for the rules R23 and R24, the output fuzzy set U_{M_p} will be ponderated with $\omega\, U_{M\_p}$ coefficient calculated in this way:

$$\omega U_{M\_p} = MAX (\omega_{23} , \omega_{24}) = $$
$$MAX (0.37 , 0.5) = 0.5 \qquad (24)$$

The form of each activate fuzzy set from entire domain of output variable, depends on used "coding" diagram.
We will use a coding process with correlation by product, according to the fuzzy output of the system result by the multiplication of the affiliation functions of the output variable, with activation scalar value of i referred rule.

For supposed example the fuzzy output of the system is:

$$0 = MAX (\omega_{18} , \omega_{19})\, m_{Umd\_p} +$$
$$+ MAX(\omega_{23}, \omega_{24})\cdot m_{UM\_p} \qquad (25)$$

which geometrical is summarized to the reunion of determinate areas by fuzzy sets resulted from coding, figure 4.

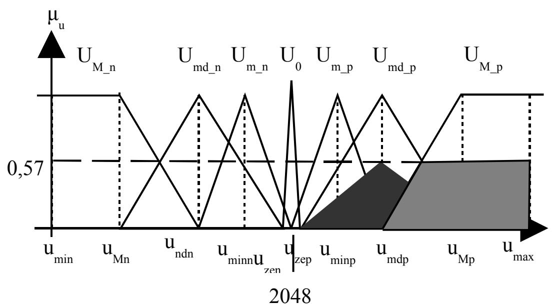


Fig. 4 Output fuzzy set

UNFUZZYING VAGUE INFORMATION

In this application we opted for the most used method of unfuzzying, which offer the most consistent results, *the weight center method (centroid)*. According with this, if output fuzzy sets are determinate by the inference method with product correlation, then we may calculate global weight center from local weight centers of each i rule from BRF, as:

$$u_k = \frac{\omega_{U_{M\_n}} I_{U_{M\_n}} c_{U_{M\_n}} + \omega_{U_{md\_n}} I_{U_{md\_n}} c_{U_{md\_n}} + \ldots}{\omega_{U_{M\_n}} I_{U_{M\_n}} + \omega_{U_{md\_n}} I_{U_{md\_n}} + \ldots + \omega_{U_{M\_p}} I_{U_{M\_p}}}$$
$$\frac{\ldots + \omega_{U_{M\_p}} I_{U_{M\_p}} c_{U_{M\_p}}}{\omega_{U_{M\_n}} I_{U_{M\_n}} + \omega_{U_{md\_n}} I_{U_{md\_n}} + \ldots + \omega_{U_{M\_p}} I_{U_{M\_p}}} \qquad (26)$$

where:

- ω_i is activation scalar value of i rule from BRF;
- I_i is surface area (triangle area or trapezoidal area);
- c_i is the ordinate of weight center of output fuzzy set fit to i rule.

For this numeric case the value of output is:

$$u_k = \frac{\omega_{U_{md\_p}} I_{U_{md\_p}} c_{U_{md\_p}} + \omega_{U_{M\_p}} I_{U_{M\_p}} c_{U_{M\_p}}}{\omega_{U_{md\_p}} \cdot I_{U_{md\_p}} + \omega_{U_{M\_p}} \cdot I_{U_{M\_p}}} =$$
$$= \frac{0,5 \cdot 333,3 \cdot 2762,2 + 0.5 \cdot 583,2 \cdot 3620}{0,5 \cdot 333,3 + 0,5 \cdot 532} = 3095,9 \qquad (27)$$

Because the number obtained is a real number and digital – to – analogical converter work only with integers, the value 3095,9 is rounded to proximate integer, that is 3096.

In figure 5 is represented the command interface of the experimental system implemented in LabWindows CVI. On this interface can observe the shape of the real response of positional system to few variation of position reference. The small variation of the system response around reference in stationary condition is due to impreciseness of the position resistive transducer.

Fig. 5 Interface with real response of the system

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CONCLUSIONS

The control fuzzy algorithm implemented in this example with LabWindows CVI software offers betters performances so in transitory condition and in the stationary condition than classic PID algorithm. (this is based on practice) being visible the fuzzy control anticipation effect of next evolution of the piston. The advantage comes even from capability to modify the variation interval of linguistic defined terms, the capability offered by relations (6), (12), (19).

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