Fuzzy Control Algorithm Implementation using LabWindows

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Abstract: - This paper presents the way to create a fuzzy controller used to command a fluid flow servo-valve with force reaction, this servo-valve being the execution element of an industrial robot 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 controller 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.

Key-Words: - fuzzy algorithm, servo-valve, industrial robot, implementation, LabWindows environment

1 Introduction
In an advanced industrialized society the modern technology supposes the complex automation of the productive processes based on the use of the artificial intelligence. The increase of the nomenclature of the created pieces and the decrease of the relative rate of the bulk and serial production because of the small serial production and unique production leads to new automation means.

If the conventional conveyors created for a single goal can’t efficiently solve this problem, the industrial robots are the ones which resolve it.

In the last years, a significant increase of the number of various fuzzy applications has been notice. Applications of this type have extended upon different domains that use robots [1], 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.

The industrial robots are general electro-pneumatic-hydrokinetic systems having more degrees of freedom, able to perform handling operations independently and automatically under the control of a command system equipped with a programming memory [2].

Including of a microprocessor in a control and measure system gives the opportunity that the manoeuvres of the operator to be taken by the microprocessor and additionally to obtain some important advantages:
- The taking over of the operator commands such as zero adjust and scale adjustment, the scale selection assuring a plus of accuracy and safety in exploitation [3], [4].
- Self-calibration and automatic equalization of the effect of the climate factors. Also are calculated the errors and the final result of the measurement is corrected.
- The improvement of the accuracy by abstraction the systematic errors (by self-calibration, self-correction).
- The decrease of the system components numbers by removing the components for the implementation of the hardware control.
- The increase of the versatility of the apparatus by obtaining some additional possibilities of measure based on the internal programs.
- The increase of the working speed by automation the measuring operations [5].
- The possibility of estimation by calculus of the other signal parameters (peak value, mean value, effective value, the calculus of the distortions, of the amplitudes spectrum, the estimation of the phase, the estimation of the phase difference).
- The possibility of self-testing by special programs performed by the incorporated microprocessor at the operator command or in case of appearance some functional anomaly. In this case
can be unleashed a testing and signalling procedure of the eventually faults [6].

All these advantages clearly show that the modern control and measure systems can not exist without being controlled by microprocessors.

The experimental model (fig. 1) 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 used servo-valve 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.

ATMEL offers a wide range of microcontrollers. A part of the devices have the advantage of a high speed of the nucleus which double the frequency of the internal clock for CPU. Also includes products with specific applications with special functions for using on the specialized markets: NAC network, MP3 applications [7].

ATMEL offers microcontrollers on 8/18 bits based on a strong architecture. The devices ATMEL do not need special knowledge of programming. So, they open the way to a much largest class of potential users. They are relatively a few input/output lines, a limited instructions set and almost without peripherals are convenient for control applications.

The control of the process is made with the help of the computer through an acquisition and control board which is based on a ATME 89C52 microcontroller, and which communicates with the calculus system though the serial port [8].

The acquisition system has: an analo gical input to read the potentiometer, an analogical output for the numerical-analogical converter which controls the servo-valve and a serial communication channel for the connection with the computer.

2 Technical Characteristics of the Robot

The technical characteristics of the industrial robot include: the dimensions, the values of the workable displacements, the accuracy, the repeatability, the numbers of degrees of freedom, the action time, the robot weight, the volume of the working space, the capacity of the command and control system, the speed, the transportable load, the working conditions, the possibility to dispose of more working arms [9, 10].

In general, the performances of the industrial robots can be appreciated using global parameters defined as it follows:

- the global parameter \( k_1 \), characterizes the industrial robot from the point of view of its efficiency of interfering in the industrial environment and of its suppleness [11]:

\[
k_1 = \frac{\text{The volume of the working space (m}^3\text{)}}{\text{The duty weight of the robot (N)}} \tag{1}
\]

- the global parameter \( k_2 \), characterizes the industrial robot regarding the specific gravitational capacity of handling

\[
k_2 = \frac{\text{The weight of the handled object (N)}}{\text{The duty weight of the robot (N)}} \tag{2}
\]

- the global parameter \( k_3 \), characterizes the technical qualities of the industrial robot, these being better as \( k_3 \) is bigger

\[
k_3 = \frac{\text{The volume of the working space (m}^3\text{)}}{\text{The duty weight of the robot (N)}} \times \frac{\text{The weight of the handled object (N)}}{\text{The positioning precision (µm)}} \tag{3}
\]
3 Boards for data acquisition and control
A practical possibility much used in the building of an acquisition and control system is that of using the acquisition boards together with the adequate software, as it is shown in figure 2.

The acquisition boards are process interfaces having both acquisition functions and functions of processing and outside remittance of the signals generated by the computer. They involve all or only a part of the up presented systems together with additional functions [12], [13].

Because a good part of the computerized measure systems problems is represented by the aspects regarding to the remittance and processing of the information contained in digital signals, one of the known classifications of these systems is in accordance with the protocol used for the remittance of the digital signals.

4 Design of the Fuzzy Controller
Choosing the Linguistic Variables and Terms
In the fuzzyification process of certain information (fuzzy controller input information) are necessary the following steps:
- to define the base set (the universe of discourse) which characterized the linguistic variable: the base set defines the variation domain of the certain information;
- to define the linguistic terms which characterized the certain information; this means to define the membership function;
- to establish the membership degree of the certain value at defined linguistic.

To adjust the position of the cylinder’s piston, three linguistic variables, associated to the input quantities (position error and movement speed of the piston) and output quantities (command) are defined:
- the position error – an input linguistic variable which varies between \([emin \div emax]\) mm;
- the 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 \([vmin \div vmax]\) mm/s;
- the command – output linguistic variable which varies between \([Umin \div Umax]\).

The variation domain of the output (command) is considered in units of the numeric-analogical converter (NAC) MAX 536, used for the command of the servo-valve. This is a converter on 12 bits with differential output \((-2,5 \div +2,5)\), the domain in which the command of the fuzzy regulator varies is \((0 \div 4096)\). So:
- when a 0 command is desired, the number of NAC must be 2048;
- when a \((-2,5 \div 0)\)V command is desired, the number of NAC units must be between \((0 \div 2048)\);
- when a \((0 \div +2,5)\)V command is desired, the number of NAC units must be between \((2048 \div 4096)\).

It follows a vague representation of the position error for the variation domain \([emin \div emax]\) mm and of the movement speed of the piston for the \([vmin \div vmax]\) mm/s domain, through the affiliated functions and a vague representation of the command for the \([Umin \div Umax]\) domain.
The linguistic variables position error may be vaguely characterized through the following linguistic terms [2]:

- $\varepsilon_{Mn}$ – high negative position error - with the affiliation function:
  \[ \mu_{\varepsilon_{Mn}} = (\varepsilon_{\text{emin}}, \varepsilon_{\text{emin}}, \varepsilon_{\text{Mn}}, \varepsilon_{\text{zen}}) \]  
  (4)

- $\varepsilon_{MDn}$ – medium negative position error - with the affiliation function:
  \[ \mu_{\varepsilon_{MDn}} = (\varepsilon_{\text{Mn}}, \varepsilon_{\text{MDn}}, 0) \]  
  (5)

- $\varepsilon_{ze}$ – zero position error - with the affiliation function:
  \[ \mu_{\varepsilon_{ze}} = (\varepsilon_{\text{zen}}, 0, \varepsilon_{\text{zek}}) \]  
  (6)

- $\varepsilon_{Mdp}$ – medium positive position error - with the affiliation function:
  \[ \mu_{\varepsilon_{Mdp}} = (0, \varepsilon_{\text{Mdp}}, \varepsilon_{\text{Mp}}) \]  
  (7)

- $\varepsilon_{Mp}$ – high positive position error - with the affiliation function:
  \[ \mu_{\varepsilon_{Mp}} = (\varepsilon_{\text{zek}}, \varepsilon_{\text{Mp}}, \varepsilon_{\text{emax}}, \varepsilon_{\text{emax}}) \]  
  (8)

where $\varepsilon_{\text{min}}, \varepsilon_{\text{Max}}, \varepsilon_{\text{zen}}$ and $\varepsilon_{\text{zek}}$ are given as initial data, and other parameters are to be calculated for generality with the following relations:

- $u_{ip} = \varepsilon_{\text{max}}/3; u_{in} = \varepsilon_{\text{min}}/3; \varepsilon_{\text{min}} = -250; \varepsilon_{\text{Max}} = 250$;
- $e_{\text{Man}} = 2 * u_{ip}; e_{\text{MDn}} = u_{in}; e_{\text{Mdp}} = u_{ip}$;
- $e_{\text{Map}} = 2 * u_{ip}; e_{\text{zen}} = -100; e_{\text{zek}} = 100$;
  
  (9)

As it is observed in fig. 3a 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 $\varepsilon_{\text{Mn}}, \varepsilon_{\text{MDn}}, \varepsilon_{\text{Mp}}$ is like a trapeze, and for the linguistic terms $\varepsilon_{\text{MDn}}, \varepsilon_{\text{MDp}}, \varepsilon_{\text{ze}}, \varepsilon_{\text{zep}}$ and $\varepsilon_{\text{mdp}}$ is triangular symmetric.

Linguistic variable speed of movement of the piston can be vaguely characterized through the following linguistic terms [3]:

- $v_{\text{Mn}}$ – high negative speed with the affiliated trapeze function:
  \[ \mu_{v_{\text{Mn}}} = (v_{\text{min}}, v_{\text{min}}, v_{\text{Man}}, v_{\text{zen}}) \]  
  (10)

- $v_{\text{MDn}}$ – medium negative speed with the affiliated triangular function:
  \[ \mu_{v_{\text{MDn}}} = (v_{\text{Man}}, v_{\text{MDn}}, 0) \]  
  (11)

- $v_{\text{ze}}$ – zero speed with the affiliated triangular function:
  \[ \mu_{v_{\text{ze}}} = (v_{\text{zen}}, 0, v_{\text{zep}}) \]  
  (12)

- $v_{\text{Mdp}}$ – zero speed with the affiliated triangular function:
  \[ \mu_{v_{\text{Mdp}}} = (0, v_{\text{Mdp}}, v_{\text{Map}}) \]  
  (13)

- $v_{\text{Mp}}$ – the high positive speed with the affiliated trapeze function:
  \[ \mu_{v_{\text{Mp}}} = (v_{\text{zep}}, v_{\text{Map}}, v_{\max}, v_{\max}) \]  
  (14)

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

- $u_{ip} = v_{\text{max}}/3; u_{in} = v_{\text{min}}/3; v_{\text{min}} = -100; v_{\text{max}} = 100$;
- $v_{\text{Man}} = 2 * u_{ip}; v_{\text{MDn}} = u_{in}; v_{\text{Mdp}} = u_{ip}$;
- $v_{\text{Map}} = 2 * u_{ip}; v_{\text{zen}} = -40; v_{\text{zep}} = 40$;
  
  (15)

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

- $U_{\text{Mn}}$ – high negative command with the affiliated trapeze function:
  \[ \mu_{U_{\text{Mn}}} = (u_{\text{min}}, u_{\text{min}}, u_{\text{Man}}, u_{\text{MDn}}) \]  
  (16)

- $U_{\text{MDn}}$ – medium negative command with the affiliated triangular function:
  \[ \mu_{U_{\text{MDn}}} = (u_{\text{Man}}, u_{\text{MDn}}, u_{\text{zen}}) \]  
  (17)

- $U_{\text{zn}}$ – low negative command with the affiliated triangular function:
  \[ \mu_{U_{\text{zn}}} = (u_{\text{MDn}}, u_{\text{min}}, 0) \]  
  (18)

- $U_{0}$ – zero command with the affiliated triangular function:
  \[ \mu_{U_{0}} = (u_{\text{zen}}, 0, u_{\text{zep}}) \]  
  (19)

- $U_{\text{mp}}$ – low positive command with the affiliated triangular function:
  \[ \mu_{U_{\text{mp}}} = (0, u_{\text{min}}, u_{\text{MDp}}) \]  
  (20)

- $U_{\text{Mdp}}$ – medium positive command with the affiliated triangular function:
  \[ \mu_{U_{\text{Mdp}}} = (u_{\text{zep}}, u_{\text{Mdp}}, u_{\text{Map}}) \]  
  (21)

- $U_{\text{Mp}}$ – high positive command with the affiliated trapeze function:
  \[ \mu_{U_{\text{Mp}}} = (u_{\text{Mdp}}, u_{\text{Map}}, u_{\text{max}}, u_{\text{max}}) \]  
  (22)
To represent vaguely the linguistic variable command, are adopted the following calculus relations:

\[
\begin{align*}
    u_{\text{min}} &= 0; \\
    u_{\text{max}} &= 4096; \\
    u_{\text{zen}} &= 2000; \\
    u_{\text{sep}} &= 2096; \\
    u_{\text{in}} &= \frac{(u_{\text{zen}} - u_{\text{min}})}{3}; \\
    u_{\text{min}} &= \frac{(u_{\text{sep}} - 2048)}{2}; \\
    u_{\text{in}} &= \frac{(u_{\text{sep}} - 2048)}{2}; \\
    u_{\text{dp}} &= 2048 + u_{\text{sep}} + u_{\text{in}}; \\
    u_{\text{dn}} &= 2048 - u_{\text{zen}} - u_{\text{in}}; \\
    u_{\text{dp}} &= 2048 + u_{\text{sep}} + 2u_{\text{in}}; \\
    u_{\text{dn}} &= 2048 - u_{\text{sep}} + 2u_{\text{in}}; \\
\end{align*}
\]

(23)

The shape of the affiliated functions afferent to the linguistic terms \(U_{\text{m}-\text{n}}\) and \(U_{\text{m}-\text{n}}\) is a trapeze, while the one of the \(U_{\text{md}-\text{n}}, U_{\text{m}-\text{n}}, U_{\text{mp}}, U_{\text{md}-\text{p}}\) and \(U_{\text{0}}\) are triangular symmetric as seen in fig. 4.

![Fig.4 The shape of the affiliated functions for the linguistic variable command](image)

When the base of rules is built, following are taken 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);
- 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 the whole resulted base of rules is [4]:

\[
\begin{align*}
    \text{R1: If } (e_{\text{Mn}} \text{ and } v_{\text{Mn}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R2: If } (e_{\text{Mn}} \text{ and } v_{\text{mdn}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R3: If } (e_{\text{Mn}} \text{ and } v_{\text{ze}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R4: If } (e_{\text{Mn}} \text{ and } v_{\text{mdp}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R5: If } (e_{\text{Mn}} \text{ and } v_{\text{Mp}}) \text{ then } U_{\text{M}-\text{n}}; \\
    \text{R6: If } (e_{\text{mdn}} \text{ and } v_{\text{Mn}}) \text{ then } U_{\text{md}-\text{n}}; \\
    \text{R7: If } (e_{\text{mdn}} \text{ and } v_{\text{mdn}}) \text{ then } U_{\text{md}-\text{n}}; \\
    \text{R8: If } (e_{\text{mdn}} \text{ and } v_{\text{ze}}) \text{ then } U_{\text{md}-\text{n}}; \\
    \text{R9: If } (e_{\text{mdn}} \text{ and } v_{\text{mdp}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R10: If } (e_{\text{mdn}} \text{ and } v_{\text{Mp}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R11: If } (e_{\text{ze}} \text{ and } v_{\text{Mn}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R12: If } (e_{\text{ze}} \text{ and } v_{\text{mdn}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R13: If } (e_{\text{ze}} \text{ and } v_{\text{ze}}) \text{ then } U_{\text{0}}; \\
    \text{R14: If } (e_{\text{ze}} \text{ and } v_{\text{mdp}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R15: If } (e_{\text{ze}} \text{ and } v_{\text{Mp}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R16: If } (e_{\text{mdp}} \text{ and } v_{\text{Mn}}) \text{ then } U_{\text{md}-\text{n}}; \\
    \text{R17: If } (e_{\text{mdp}} \text{ and } v_{\text{mdn}}) \text{ then } U_{\text{md}-\text{n}}; \\
    \text{R18: If } (e_{\text{mdp}} \text{ and } v_{\text{ze}}) \text{ then } U_{\text{md}-\text{n}}; \\
    \text{R19: If } (e_{\text{mdp}} \text{ and } v_{\text{mdp}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R20: If } (e_{\text{mdp}} \text{ and } v_{\text{Mp}}) \text{ then } U_{\text{m}-\text{n}}; \\
    \text{R21: If } (e_{\text{Mp}} \text{ and } v_{\text{Mn}}) \text{ then } U_{\text{M}-\text{n}}; \\
    \text{R22: If } (e_{\text{Mp}} \text{ and } v_{\text{mdn}}) \text{ then } U_{\text{M}-\text{n}}; \\
    \text{R23: If } (e_{\text{Mp}} \text{ and } v_{\text{ze}}) \text{ then } U_{\text{M}-\text{n}}; \\
    \text{R24: If } (e_{\text{Mp}} \text{ and } v_{\text{mdp}}) \text{ then } U_{\text{M}-\text{n}}; \\
    \text{R25: If } (e_{\text{Mp}} \text{ and } v_{\text{Mp}}) \text{ then } U_{\text{M}-\text{n}}; \\
\end{align*}
\]

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.
5 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 the MAX – MIN, MAX – PROD or SUM-PROD compositions are used [5].

To understand the inference mechanism which is the base of a fuzzy regulator, the following case study is considered: 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, the affiliated functions of triangular and trapeze type are used [6].

The afferent value of the affiliation degrees of firm quantities $e=125$ to defined linguistic terms are according to relation (20).

$$e_0 = \{0, 0, 0, 0.5, 0.37\}$$

Proceeding in the same way for calculation of affiliation degrees of firm quantities $v=25$ of piston movement speed, this are according to relation (21).

$$v_0 = \{0, 0, 0.37, 0.75, 0\}$$

In any 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 ($e_{Mn}$ and $v_{Mn}$) then $U_{M,n}$

we have:

$$\omega_{U_{M,n}} = MIN(0, 0) = 0;$$

where:
$$\omega_{U_{M,n}} - \text{ is activation scalar value of fuzzy set } U_{M,n}.$$

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 ($e_{mdp}$ and $v_{ze}$) then $U_{md,p}$

For this rule the activation scalar value is:

$$\omega_{U_{md,p}} = MIN(0.5, 0.37) = 0.37;$$

R19: If ($e_{mdp}$ and $v_{ndp}$) then $U_{md,p}$

For this rule the activation scalar value is:

$$\omega_{U_{md,p}} = MIN(0.5, 0.75) = 0.5;$$

R23: If ($e_{Mp}$ and $v_{ze}$) then $U_{M,p}$

For this rule the activation scalar value is:

$$\omega_{U_{M,p}} = MIN(0.37, 0.37) = 0.37;$$

R24: If ($e_{Mp}$ and $v_{ndp}$) then $U_{M,p}$

For this rule the activation scalar value is:

$$\omega_{U_{M,p}} = MIN(0.5, 0.75) = 0.5;$$

We remark that in inference process the rules can have like result the same output fuzzy set, in generally activated by the different $\omega_i$ coefficients. This is the case of rules R18 and R19 from this example which have the output fuzzy set the command $U_{md,p}$, respectively R23 and R24 which have the output fuzzy set the command $U_{M,p}$.

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 $\omega_i$ 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:

$$\omega_{U_{md,p}} = MAX(0.37, 0.5) = 0.5$$

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:

$$\omega_{U_{M,p}} = MAX(0.37, 0.5) = 0.5$$

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 [7].

For supposed example the fuzzy output of the system is:

$$0 = MAX(\omega_{18}, \omega_{19})m_{U_{md,p}} + MAX(\omega_{23}, \omega_{24})m_{U_{M,p}}$$

which geometrical is summarized to the reunion of determinate areas by fuzzy sets resulted from coding, figure 5.
6 Unfuzzing vague information

In this application we opted for the most used method of unfuzzing, 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:

\[
 u_k = \frac{\omega_i I_{M_n}^p c_{M_n}^p + \omega_i I_{M_n}^p c_{M_n}^p + \cdots + \omega_i I_{M_n}^p c_{M_n}^p}{\omega_i I_{M_n}^p c_{M_n}^p + \omega_i I_{M_n}^p c_{M_n}^p + \cdots + \omega_i I_{M_n}^p c_{M_n}^p} = \frac{\omega_i I_{M_n}^p c_{M_n}^p + \omega_i I_{M_n}^p c_{M_n}^p + \cdots + \omega_i I_{M_n}^p c_{M_n}^p}{\omega_i I_{M_n}^p c_{M_n}^p + \omega_i I_{M_n}^p c_{M_n}^p + \cdots + \omega_i I_{M_n}^p c_{M_n}^p} = \frac{0.5 \times 333.3 \times 2762.2 + 0.5 \times 583.2 \times 3620}{0.5 \times 333.3 + 0.5 \times 583.2} = 3095.9 \quad (35)
\]

where:

- \( \omega_i \) 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:

\[
 u_k = \frac{0.5 \times 333.3 \times 2762.2 + 0.5 \times 583.2 \times 3620}{0.5 \times 333.3 + 0.5 \times 583.2} = 3095.9 \quad (35)
\]

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 transducer.

7 ATMEL reception

The ASM program for microcontroller reception [9], [10] is:

; Control reception from master
;Verify the correctness of the first byte
SERVICE: CLR ES; Infirm the serial interruption
CLR EA;
NOP ; data reception
PUSH ACC; salve the accumulator
PUSH PSW
CLR PSW.3 ;RS0=0
SETB PSW.4 ;RS1=1,
MOV R4,#5;load the data number to be received
MOV R1,#DATE_RX; load the data address to be received
MOV A,#00H;
MOV @R1,A; cancellation PREVIOUS value
INC R1;
MOV A,#00H;
MOV @R1,A; cancellation PREVIOUS value
INC R1;
MOV @R1,A; cancellation PREVIOUS value
INC R1;
MOV @R1,A; cancellation PREVIOUS value
INC R1;
MOV @R1,A; cancellation PREVIOUS value
MOV R1,#DATE_RX ; load the data address to be received
DA_REC: MOV @R1,SBUF ; read the received value
INC R1 ; Increment the data saving adress
CLR R1;Delete the reception flag
DJNZ R4,NU_ENDRX;Number of saved data
LJMP REC_OK
; Wait the reception of another byte
NU_ENDRX:NOP
CLR TR0 ; Stop timer 0
MOV TH0,#064H ; timer for 10ms
MOV TL0,#00H ;for waiting reception
SETB TR0 ; starting timer 0 for 10 ms
CLR TF0 ; Delete the timer indicator
ETY_REC:JB RI,DA_REC; a new reception?

Fig. 6 The command interface of the experimental system
INB TF0,ETY_REC ; without reception in 10 ms
LJMP COM_BAD;
; Verify correctness + CRC
REC_OK: CLR TR0
    MOV R1,#DATE_RX ; load the data address to be delivered
    MOV REC1,@R1; Save data
    INC R1 ; load the data address to be delivered
    MOV REC2,@R1; Save data
    INC R1 ; load the data address to be delivered
    MOV REC3,@R1; Save data
    INC R1 ; load the data address to be delivered
    MOV REC4,@R1; Save data
    INC R1 ; load the data address to be delivered
    MOV REC5,@R1; Save data
; Verify CRC
    MOV A,REC1; load with the first byte
    ADD A,REC2; add the second byte
    ADD A,REC3; add the third byte
    ADD A,REC4; add the fourth byte
    CJNE A,REC5,COM_BAD; compared to the fourth
    MOV A,REC5; load with the first byte
    CJNE A,#32H,COM_BAD ; compared with the fifth
; Verify the header of the data package
    MOV A,REC1; load with the first byte
    CJNE A,'#V',COM_BAD; Failed communication
; Verify the second data byte
    MOV A,REC2; load with the second byte
    ANL A,#01111111B;
    MOV REC2,A;
    CLR C ; delete carry
    SUBB A,IMP_TOT; subtraction A-100
    JC REC2_OK;
    MOV REC2,#100 ; if A>100 => A=100
REC2_OK: MOV IMP_TOT,REC2; Save the impulse period
; Verify the third data byte
    MOV A,REC3; load with the third byte
    ANL A,#01111111B;
    MOV REC3,A;
    CLR C ; delete carry
    SUBB A,IMP_TOT; subtraction A-100
    JC REC3_OK;
    MOV REC3,IMP_TOT; if A>100 => A=100
REC3_OK: MOV IMP_M1,REC3; Save the impulse time
    MOV A,IMP_TOT; A=NT IMP TOTAL
    CLR C ; delete carry
    SUBB A,IMP_M1; subtraction A-IMP_M2
    MOV IMP_M1,A; Save NO. OF IMPULS ON 0
; Verify the fourth data byte
    MOV A,REC4; load with the fourth data byte
    MOV C,ACC.7; load the working sense
    MOV SENS_M2,C; load the working sense
    ANL A,#01111111B;
    MOV REC4,A;
    CLR C ; delete carry
    SUBB A,IMP_TOT; subtraction A-100
    JC REC4_OK;
    MOV REC4,IMP_TOT; if A>100 => A=100
REC4_OK: MOV IMP_M2,REC4; Save the impulse time
    MOV A,IMP_TOT; A=NT IMP TOTAL
    CLR C ; delete carry
    SUBB A,IMP_M2; subtraction A-IMP_M2
    MOV IMP_M2,A; Save NO. OF IMPULS ON 0
; All the bytes are verified => everything is OK
    SETB RX_OK ; Reception OK
    MOV TXD1,'#R'; Load delivered data
    MOV TXD2,'#O'; Load delivered data
    MOV TXD3,'#K'; Load delivered data
    MOV TXD4,#0DH; Load delivered data
    LJMP TX_DATE ; DELIVERED DATA
; Error communication
    COM_BAD: CLR RX_OK ; ERROR RECEPTION
    MOV TXD1,'#E'; Load delivered data
    MOV TXD2,'#R'; Load delivered data
    MOV TXD3,'#R'; Load delivered data
    MOV TXD4,#0DH; Load delivered data
    LJMP TX_DATE ; DELIVERENCE DATA;-------
TX_DATE:NOP
SETBTI ;For fuctioning with breaking
MOV CRC,#00H ; initialization for CRC calculus
MOV TEMP,TXD1 ;load TXD1
TX_CRC TEMP;deliver TXD1
MOV TEMP,TXD2 ;load TXD2
TX_CRC TEMP;deliver TXD2
MOV TEMP,TXD3 ;load TXD3
TX_CRC TEMP;deliver TXD3
MOV TEMP,TXD4 ;load TXD4
TX_CRC TEMP;deliver TXD4
TX_CRC CRC;TX CRC
JNB TI,$ ;waiting delivery CRC CLR TI ; Delete transmission flag
CLR RI ; Delete reception flag
CLR PSW.3 ;RS0=0
CLR PSW.4 ;RS1=0,
POP PSW
POP ACC;
SETB ES
SETB EA
RETI ; come back from the serial breaking.

8 Industrial robots programming in LabWindows/CVI environment

LabWindows/CVI is an environment for developing new applications using the programming language ANSI C. It is ideal for industrial automation, measurements and offers the possibility to store process data. The debugger offers the possibility to import the Borland C++ Builder 4.0 and Visual C++ 6.0 libraries and generate the code of the design interface.

9 Conclusion

Fuzzy control 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 (9), (15), (23).

References:


