Design and Implementation of Fuzzy Logic Controller for IVAX SCARA Robot Using Real Time Window Target

Mohammed Z.AL- Faiz, Ayam M.Abbass
Computer Engineering Department,
College of Engineering, Al-Nahrain University,
Baghdad, Iraq

Abstract- **In this paper Two types of controllers are designed and implemented, they are PID controller and fuzzy like PD controller for IVAX Selective Compliance Assembly Robotic Arm (SCARA) Robot (4 DOF).The controllers are designed to reach the joints of IVAX SCARA Robot to desired position with specific orientation. Each joint of the robot is treated as a Single Input Single Output (SISO) system. The interface card is design and implemented to connect the IVAX SCARA Robot with the PC computer via multi function card (PCI-1711U), which is supported by Simulink/Real Time Window Target (RTWT) and it will be used for the controller creation and solution. The system programs are built with Simulink/ Real Time Window Target (RTWT) using Matlab (2011a).**
Keywords-Fuzzy Logic Controller, SCARA Robot Arm, Real Time Window Target.

I. INTRODUCTION

Robotic manipulators have been widely used in the industrial applications. Most of these applications are restricted to slow motion operations without interactions with the environment. This is mainly due to Limited performance of the available controllers in the market that are based on simplified system models. To increase the operation speed with more servo accuracy, advanced control strategies are needed. Consideration of the actuator dynamics in the controller design is one of the possible ways to improve system performance. Although some of the industrial robots are driven by hydraulic or pneumatic actuators, most of them are still activated by motors [1].
The fundamental elements of tasks performed by robot manipulators are [2]
1. Moving the end effector, with or without a load, along a desired trajectory.
2. Exerting a desired force on an object when the end effector is in contact with it.

II. THE STRUCTURE OF SCARA ROBOT AND THE CHARACTERISTICS OF IVAX SCARA ROBOT.

A. SCARA Robot

SCARA robot is a special subclass of the cylindrical robot family. A SCARA robotic arm allows for 4 DOF the X-Y plane via two parallel, rotational joints; freedom in the Z plane via one vertical, linear joint, and the freedom to rotate the end effector about the Z axis.
The development of the SCARA robotic arm began in the early 1960's in Japan, however introduction of the robotic arm for industrial use did not begin until 1979.SCARA robotic arms primarily used in situations where the process requires high accuracy, and has a fast cycle time, which is why SCARA robotic arms are popular as part of electronics equipment assembly lines. SCARA robotic arms have also been employed in various other industrial areas such as pick and place type operations, automated palletizing, and de palletizing operations. Popularity of the SCARA robotic arm is due to its relative simplicity to control. The simply construction of the robotic arm translates into simple kinematics which are controlled by 4 independent actuators (usually 4 dc, or stepper motors). To control the positioning of a SCARA robotic arm in Cartesian Co-ordination relative to a datum point, a controller need only to observe the angles of each arm relative to the base of the robot, and through fundamental trigonometric calculations, the position of the end effector may be determined. Therefore, the processor requirements of the controller can be relatively minimal [3].

B.IVAX SCARA Robot

The arm called IVAX is intended for education market and industrial training, but the designers are confident that it will prove suitable for light industrial use as well. The SCARA robot works in a horizontal plane with two rotating axes moving up and down a central pillar. It also has a rotating wrist, making four axes with a gripper. The three rotational axes can move through 270 degrees with the vertical axis having a range of 40 mm.The arm can reach objects in an arc with a radius of between 280 mm and 108 mm. It is powered by DC servos with optical encoders providing positional feedback. Contact torque springs have been used to prevent the effect of backlash.
The end effector of the arm is a pneumatic gripper controlled by an electronic solenoid valve. It has a carrying capacity of 1kg, but it has been known to manage heavier loads. Fig.1 shows IVAX SCARA Robotic Arm [4]. The first joint of IVAX SCARA Robot is shoulder ,the second joint is elbow,the third joint is prismatic joint and the fourth joint is wrist joint .The IVAX SCARA Robot has 4 DC motors, the first three motors having number (9904-120-52602) and fourth DC motor has number (9904-120-52602).

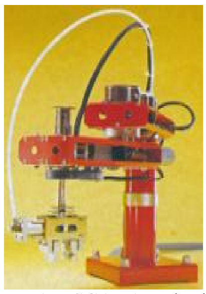

Figure1. IVAX SCARA Robotic Arm.

C. Optical Encoder and Incremental Encoder

Encoders provide motion control systems information on position, count, speed, and direction. As the encoder shaft rotates, output signals are produced, proportional to the distance (angle) of rotation. The signal may be in the form of a square wave (for an incremental encoder) or an absolute measure of position (for an absolute encoder) [5].

Incremental encoders are the most common feedback devices for robotic systems. They typically output digital pulses at TTL levels. Rotary encoders are used to measure the angular position and direction of a motor or mechanical drive shaft [6]. The basic construction of an incremental encoder is shown in the Fig.2. A beam of light emitted from an LED passes through a transparent disk patterned with opaque lines, and is picked up by a photodiode array. The photodiode array (also called a photo sensor) responds by producing a sinusoidal waveform which is transformed into a square wave, or pulse train [5].

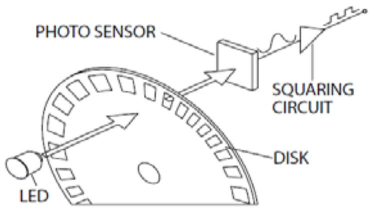

Figure2.Thebasic construction of an incremental encoder.

III. Fuzzy Logic Controller (FLC)

The fuzzy controller, (as explained in Fig.3), has four main components [7]:

1. The Rule-Base holds the knowledge, in the form of a set of rules, of how best to control the system.
2. The inputs so that they can be interpreted and compared to fuzzification Interface simply modifies the rules in the rule-base.
3. The Inference Mechanism evaluates which control rules are relevant at the current time and then decides what the input to the plant should be.
4. The Defuzzification Interface converts the conclusions reached by the inference mechanism into the inputs to the plant .

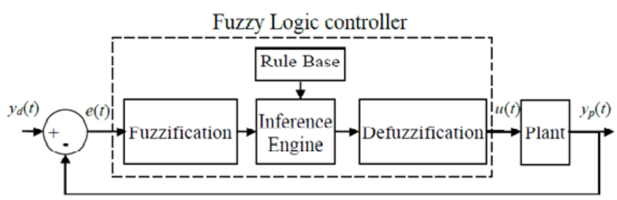

Figure 3. Typical fuzzy controller structure.

IV. The Proposed Control System

The IVAX SCARA Robot was considered as four independent joints (four control loops) which form 4 SISO systems. Each of these SISO systems is controlled independently by either PID controller or FLC controller. Such control schemes are adopted because they provide a good tradeoff between ease of implementation and performance. Fig.4 shows a block diagram of the proposed control system. The proposed control system consists of two main blocks (PC and IVAX SCARA Robot) that are connected through an interface card and supplied by a power supply. The control algorithm is built in the Matlab/Simulink software and compiled with RTWT. The Real-Time Window Target Toolbox includes a digital input and digital output that provide connection between the data acquisition card (PCI-1711U) and the simulink model.

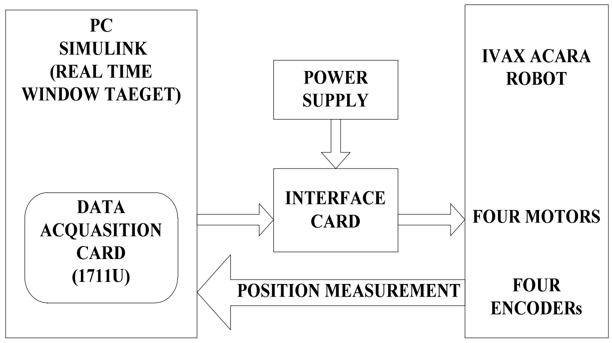

Figure 4. A block diagram of the proposed control system.

A. Hardware Components of the Proposed Control System

The hardware interfacing part of the system comprises two I/O devices, the first is an Advantech PCI-711U multifunction card and the second is a custom made interface card. The PCI-711U was installed on an PCI bus in PC,where a PC application(RTWT) controls the input and output signals of the card. The two cards are connected together by using an adapter PCLD-8710 by means of using PCL-10168, which is 68-pin SCSI-II cable and it is used to carry the digital signals between the interface card and PCI-1711U.

The interface card is connected to the IVAX SCARA Robot system by three DB-15 custom cables, one cable is dedicated for output the driving digital signals and two others cables are dedicated for input the feedback signals from IVAX SCARA Robot system. The I/O cards and their connections are depicted in Fig.5.

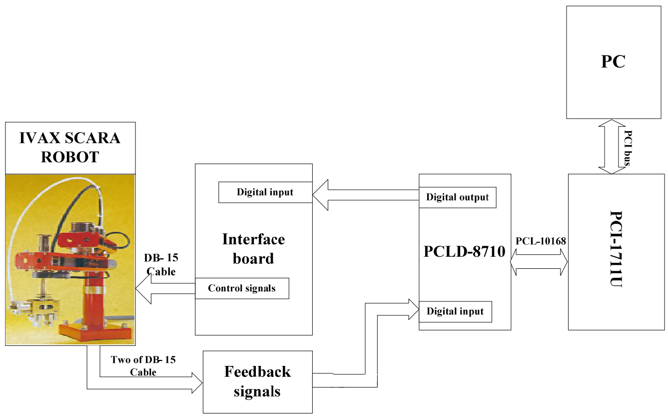

Figure 5. IVAX SCARA Robot Hardware Structure.

The communication between the computer running Simulink/Matlab and IVAX SCARA Robot is made by using the multi function card (PCI-1711U) ,which is recognize by Matlab and supported for real time applications.for more details about PCI-1711U see [8] and [9].The PCI-1711U and the PCLD 8710 are shown in Fig.6 [8].

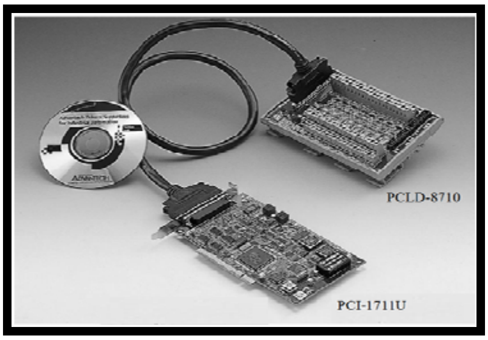

Figure 6. The PCI-1711U and the PCLD-8710.

The interface card is the second stage of the IVAX SCARA Robot interfacing circuitry. It converts the signals received from the PCI-711U card into driving signals that control the joints actuators of the IVAX SCARA Robot system.The interface card consists of four buffers of IC 74LS244 which are used as protection circuitry and buffering stages as damage prevention for the PCI-1711U and PC. The interface card contains two drivers of IC L298 which are used for feeding the joints of IVAX SCARA Robot with actuating signals for driving them. Each driver used for driving two joints and the input to the driver is six digital signals, two of (en, IN1 and IN2) where (en) is enable signal, IN1 and IN2 are signals for direction. The outputs of each driver are four signals ,each two of them using for providing the actuating signals for driving the joint in clockwise(CW) or in counter clockwise(CCW).The block diagram of interface card is shown in Fig.7 ,the interface card is shown in Fig.8.

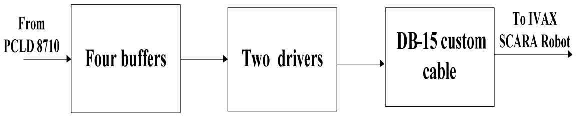

Figure 7.The Block Diagram of Interface Card.

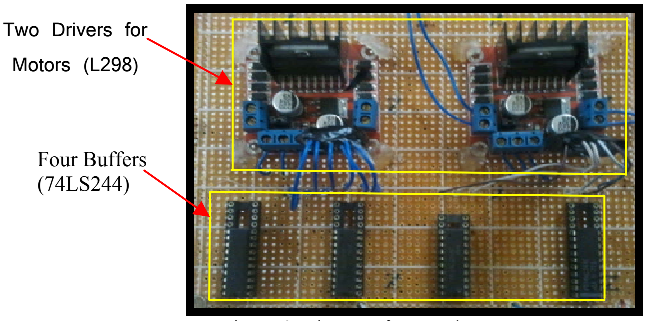

Figure 8. The Interface card.

B. Software Components of the Proposed Control System
RTWT is the software that it is used to build the software of the proposed control system. RTWT package in Matlab has the most powerful component called Kernel, which is actually a miniature Real Time Operating System (RTOS), piggybacking on the Windows. The highly optimized real time Kernel provides real time extension for Windows and allows real time execution of the compiled code within the RTWT environment. The Kernel runs at Ring 0 (highest priority) in the Windows environment and supports single or multi tasking. RTWT is actually a suite of software which permits [10]

1. The execution of the controller codes in real time.
2. Manages its input & output with the external world through an I/O board and.
3. Manages communication with the Matlab/Simulink parameter setting functions and display devices [14].

RTWT contains a set of target files that enables to generate and build a binary file for use in specific target environment [10].

Typical applications for the Real-Time Windows Target include [11]:

1.Real-time control:create a prototype of automotive, computer peripheral, and instrumentation control systems.

2.Real-time hardware-in-the-loop simulation creates a prototype of controllers connected to a physical plant. For example, the physical plant could be an automotive engine. Create a prototype of a plant connected to an actual controller. For example, the prototyped plant could be an aircraft engine .

Simulink's Real Time Windows Target is a way of creating a model for the system to be controlled by simple Drag & Drop blocks that make up the system, the use of this library requires knowledge and understanding of the Interface Card (I/O card) that is used to provide a hardware link between the device to be controlled and the computer,Target Load Compiler (TLC), The user simply makes up the block representation of the system to be controlled and Simulink generates the C-code and all of the necessary interactive codes to link the blocks with the Physical system[11].The process of creating and running a real-time application includes the creation of a Simulink model[12]:

1. Creating a Simulink model.
2. Entering configuration parameters for Simulink.
3. Specifying a default Real-Time Windows Target configuration set.

The Key Features of RTWT [13] :

1.Real-time closed-loop execution of simulink models on Microsoft Windows.

2.signal visualization and parameter tuning while model is running.

3.Execution control directly from simulink, creating a PC-in-the-loop prototyping environment.

4.Real-time performance approaching 500 Hz in normal execution mode.

5.Real-time performance approaching 20 kHz in external execution mode (with Simulink Coder).

6.Blocks supporting more than 250 I/O modules (including analog I/O, digital I/O, counters, encoders, and frequency output) and communication protocols (including UDP, serial, and CAN).

Before building the program for the proposed controller there are two steps must be achieved, these steps are:

- Install Advantech PCI-1711U and its drivers in PC.
-Install Real Time Kernel.
- Register PCI-1711U in Matlab.

The program for each proposed controller for each joint consists of two parts:

1. Driving part

The driving part of the program for each joint consists of

-Digital Pulse Width Modulation (DPWM) is a sub system which is used for controlling the voltage value that is applied to DC motor of joint which effects on DC motor speed. PWM consists of Quantizer block, Saturation block and Analogue PWM subsystem which contains Repeating sequence block and Relay block .The DPWM is shown in Fig.9.

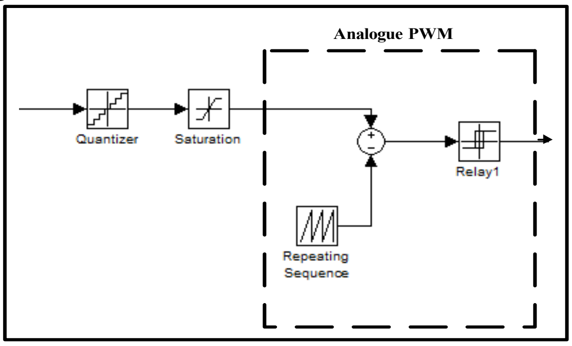

Figure 9. Digital Pulse Width Modulation (DPWM).

-Digital input and output objects

Digital input and output objects which are Simulink blocks in RTWT. In the proposed control program for one joint there are three digital output objects for driving the joint. One of them objects is for feeding the dc motor with actuating signal and the other two digital output objects are used for feeding the DC motor with direction signals. There are two input digital objects for each joint, the feedback for each DC motor is two signals which are entered to the two digital input objects.

2. Control Part

The control part consist of three embedded blocks (user defined functions).The two feedback (A and B) for each joint (feedback from incremental shaft encoder) of IVAX SCARA Robot are 90° out of phase, one signal will lead the other as the incremental shaft rotates. If signal A leads signal B the incremental shaft encoder rotates in clockwise (CW) as shown Fig. 10.a. If signal B leads signal A the incremental shaft encoder rotates in counter clockwise (CCW) as shown Fig.10.b.Where CH1 represent signal A, CH2 represents signal B.

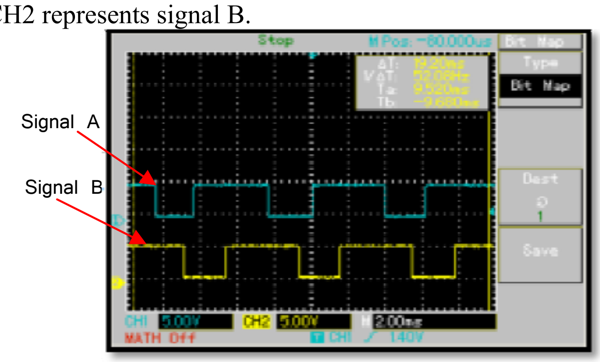

Figure 10.a.The Feedback of Shaft Encoder for one joint (CW).

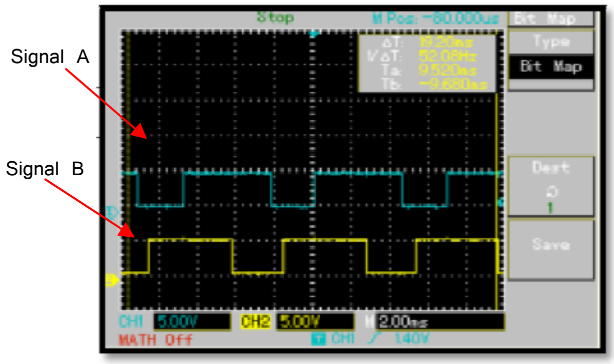

Figure10.b.The Feedback of Shaft Encoder for one joint (CCW).

Signal A is used to count the number of pulses which are the feedback from one joint of IVAX SCARA Robot .Each pulse equal 0.3 degree of theta, the equation which is used to find current theta is

Theta (in degree) = n * 0.3 (4)

n is the number of pulses which is the feedback from one joint .Signal B is used to decide if n is incremented or decremented in count.

The second function block used for build the controller, the output of controller is used as input value to the PWM in driving part of program.

The third function block is used for building subprogram for converting the pulses number to theta value in radian and degree measurement by using equation (4) and the following equation

Theta (in radian) = Theta in degree * (pi/180) (5)

A block diagram showing the proposed controller (PID controller or fuzzy controller) for single joint of Ivax IVAX SCARA Robot is shown in Fig.11.

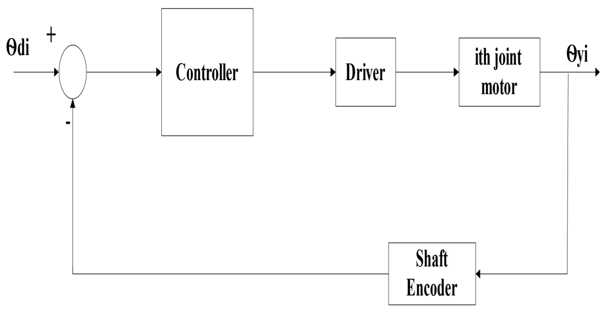

Figure 11. A block diagram of PID controller for one joint.

The actuating signal is fed to the motor controller via the driver .The controller output was limited to 12-volts to meet the physical joints motor specifications. A block diagram showing the 4 controllers (PID controller or Fuzzy controller) that were used to control the position of the end effector is shown in Fig. 12.

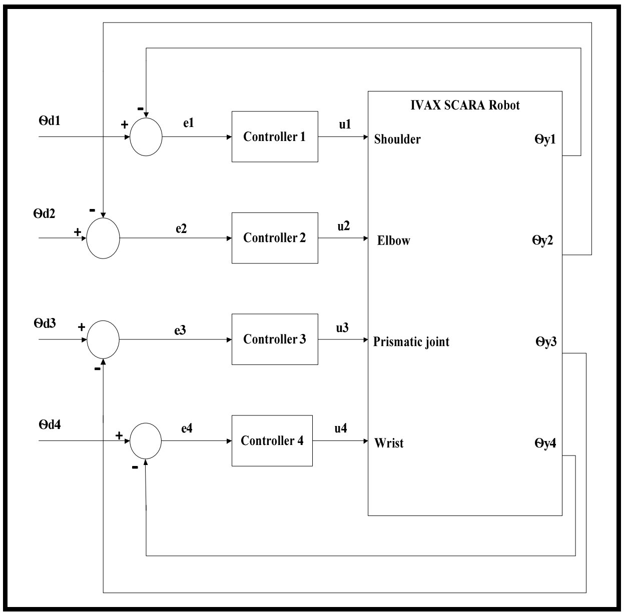

Figure 12. IVAX SCARA Robot Controllers.

V. PID CONTROLLER AND THE PROPOSED FLC

A. PID controller

PID controllers are widely used in industrial control application due to their simple structures, comprehensible control algorithms and low cost. The proposed PID controller is an implementation of a linear parallel (non-interacting) PID controller. In order to control the operation of the IVAX SCARA Robot, 4 independent PID controllers were used. Each controller interacted with a single joint of the IVAX SCARA Robot. The control process starts by sensing the angular position of each joint, then the PID controller computes the actuator command to correct the positional error of that joint.

The general form of PID controller is

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de}{dt} \qquad (6)$$

Where K_p is the proportional gain, K_i is the integral gain and K_d is the derivative gain, u(t) is the control signal and e(t) called the error signal defined as e(t) =r(t)- y(t), r(t) is the input set point that the system need to converged to it, and y(t) is the real time feedback signal that has been measure.

A proportional controller has the advantage of providing a small control variable when the control error is small and therefore to avoid excessive control efforts. The main drawback of using a pure proportional controller is that it produces a steady-state error.

The integral action will drive the steady-state error to zero. For this reason the integral action is also often called automatic reset. Thus, the use of a proportional action in conjunction to an integral action, (PI controller), solves the main problems of the steady-state error associated to a pure proportional controller. The derivative action is based on the predicted future values of the control error.

The equation (7) represents the general form of PID in analogue controller, but the PID controller that is proposed for the IVAX SCARA Robot is digital, then the derivative term may be replaced with a backward difference and the integral term may be replaced with a sum. For small constant sampling time T_s , equation (7) can be written as:

$$u(n) = K_p\, e(n) + K_i \sum e(n) * T_s + K_d\, (e(n) - e(n-1)) / T_s \qquad (7)$$

where n represents the number of current sample.

The program of the proposed PID controller is built in Simulink /Matlab and compiled with RTWT.In control part of the program, the values of error, change of error and sum of error are computed according to the following equations:

$$\text{Error}(n) = (\text{despos} - \text{curpos}) / \text{despos} \qquad (8)$$

where despos represents the desired position,curpos represents the desired position.

$$\text{Change of error} = (\text{error}(n) - \text{error}(n-1)) / T_s \qquad (9)$$

$$\text{Sum of error} = \sum e(n) \times T_s \qquad (10)$$

The value of control action of PID controller is computed by using equation (8), and then it is fed to DPWM for driving the DC motor of the joint. The program of the proposed Position control with PID controller for one joint of IVAX SCARA Robot is shown in Fig. 13.

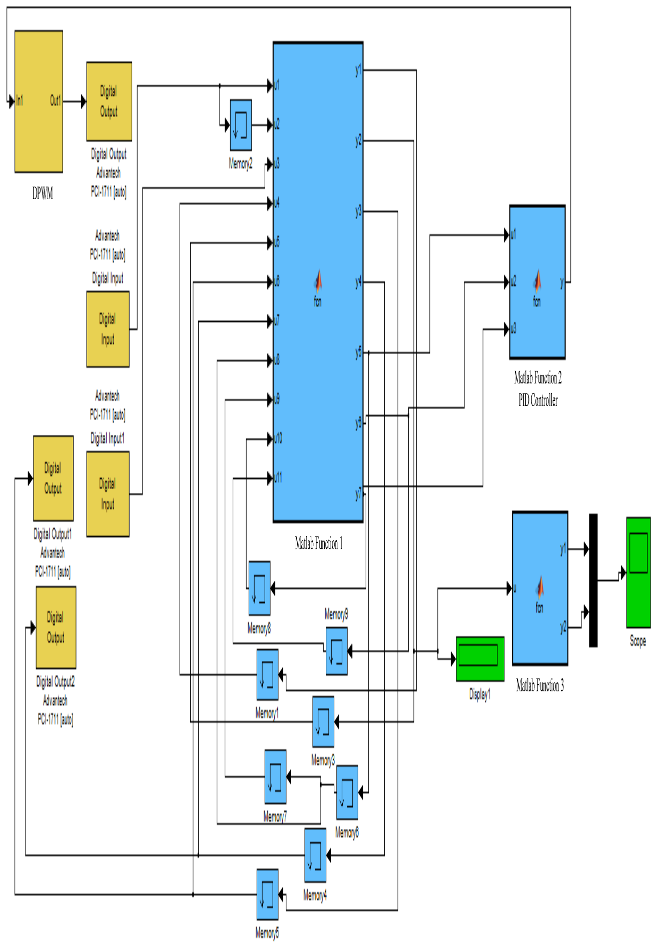

Figure 13. The Proposed position control with PID controller for one joint.

B. The proposed FLC

The implementation of FLC requires the choice of four key factors, number of fuzzy sets that constitute linguistic variables, mapping of the measurements onto the support sets, control protocol that determines the controller behavior and shape of membership functions. Thus, FLCs can be tuned not just by adjusting controller parameters but also by changing control rules, membership functions etc.
The proposed fuzzy logic like PD controller for one joint DC motor of IVAX SCARA Robot is shown in Fig. 14.

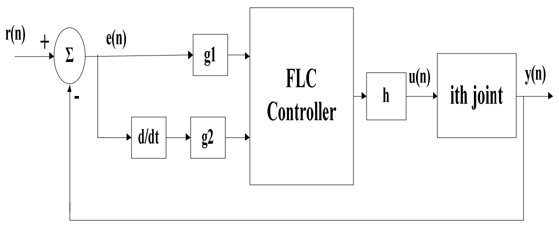

Figure 14. Fuzzy logic like PD controller for one joint.

Where g1, g2 are the scaling factors which are multiplied by the values of error and change of error respectively, and h is scaling factor where the output of fuzzy controller is multiplied with, r(n) the input set point that the system need to converged to it, and y(n) is the real time feedback signal that has been measured at sample n,e(n) and u(n) are the error value and the control action of FLC at sample n. All membership functions for the conventional fuzzy controller inputs (e and Δe) and the controller output are defined on the common normalized domain [-1, 1].
The proposed fuzzy logic like PD controller is fuzzy logic controller with five membership function linguistic variable (MSF) for the input and output with triangle shape, The FLC which is used has two input (error and change of error) which represented by five triangle MSF (NB, NS, ZE, PS, and PB) .Center of gravity (COG) which is the defuzzification method used in proposed controller. The proposed fuzzy rule base is shown in Fig.15, the input membership function for error and change of error are shown in Fig.16 and the output membership function is shown in Fig.17.

e / Δe	NB	NS	ZE	PS	PB
NB	NB	NB	NS	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PS	PB	PB

Figure 15. Fuzzy rule base.

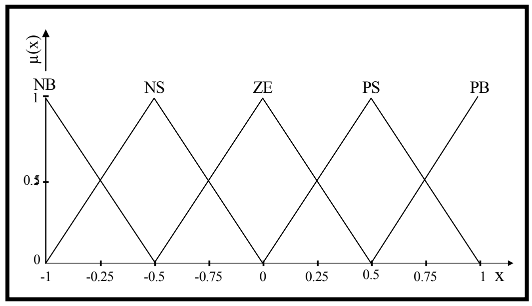

Figure 16. Input membership function for error and change of error of FLC.

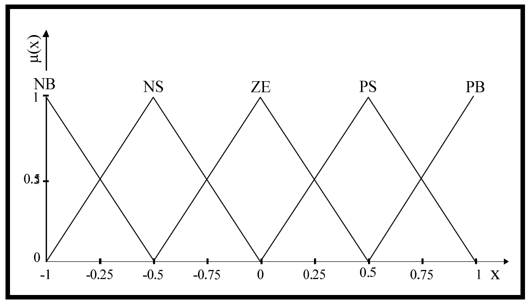

Figure 17. Output Membership Function for Error and Change of Erroror of FLC.

The control action of fuzzy controller u(n) is fed to DPWM for driving the DC motor of the joint. The program of the proposed Position control with fuzzy controller for one joint of IVAX SCARA Robot is shown in Fig.19.

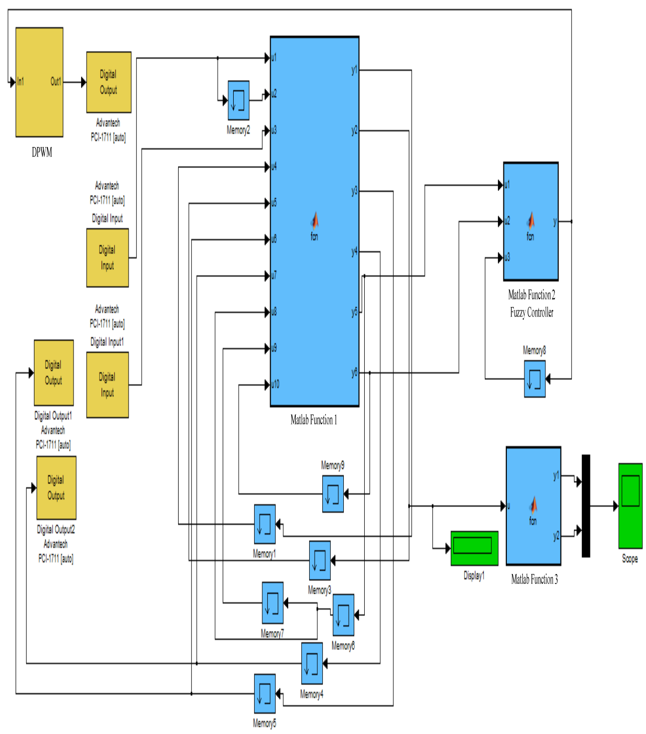

Figure 18. The Proposed Position control with Fuzzy controller for one joint.

The flowchart of position control of one joint of IVAX SCARA Robot is divided in two parts as shown in Fig.19.a and Fig.19.b.

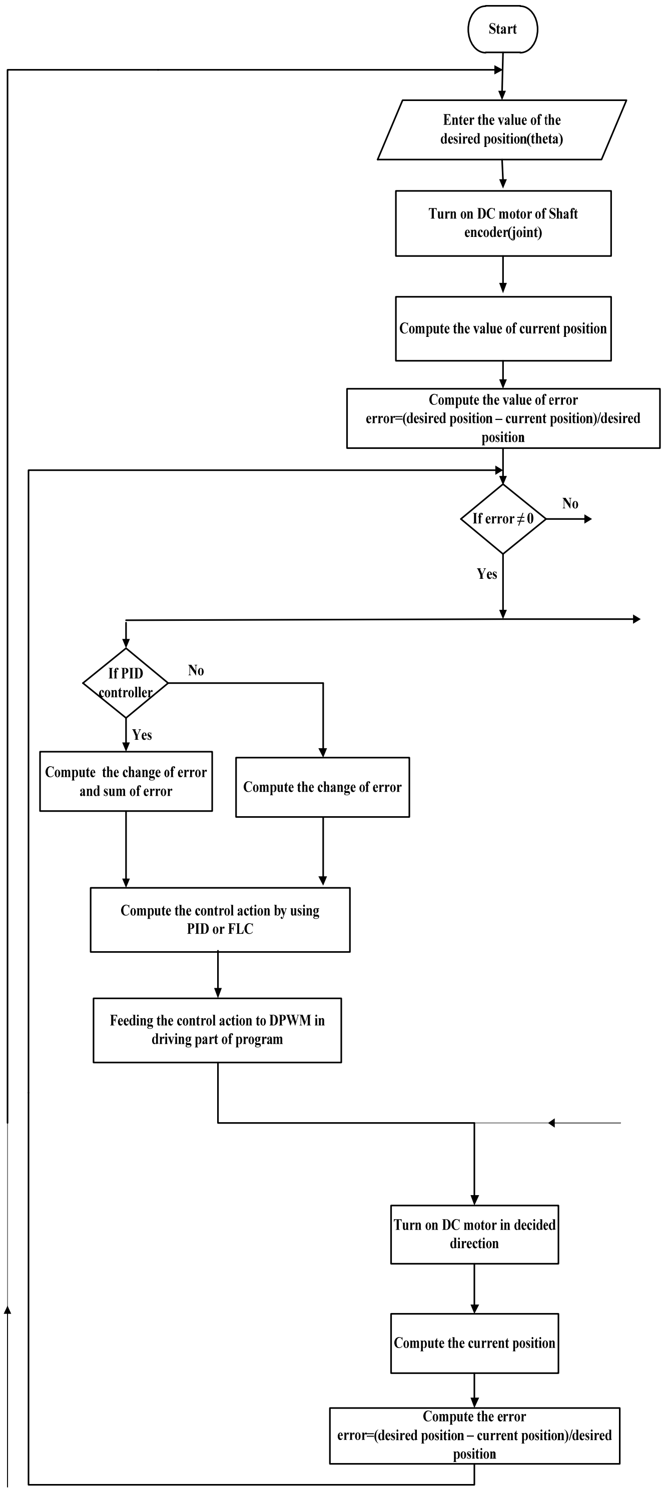

Figure 19.a. Flowchart of the position control for one joint.

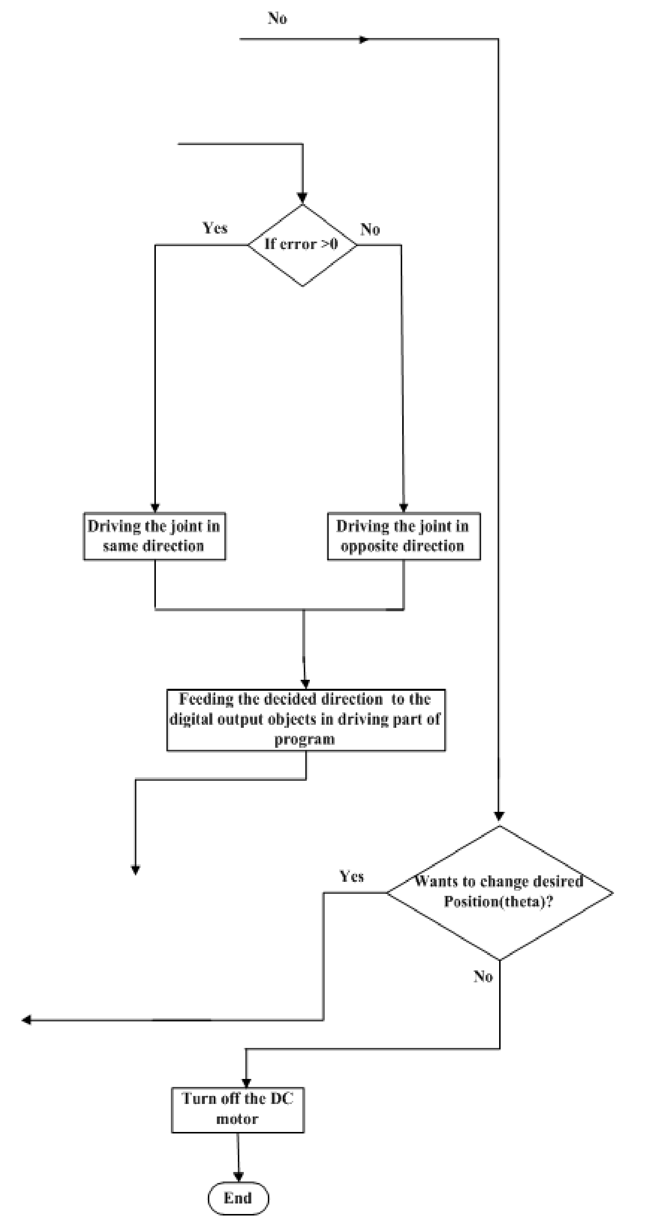

Figure 19.b. Flowchart of the position control for one joint.

VI. Implementation Results

This section is dedicated to exhibit the design specifications and simulation results of applying the PID controller and Fuzzy controller on IVAX SCARA Robot, the parameters for each controller are specified for IVAX SCARA Robot. Assuming the sampling time (T_s) = 0.001 Sec. for PID and fuzzy controllers. The values of parameters (K_p, K_i and K_d) of PID controller and the values of scaling factors (g_0, g_1 and h) for FLC are chosen by try and error method.

The response of the shoulder of IVAX SCARA Robot for moving it at theta 45 degree (0.7854 radian) is shown in Fig. 20.

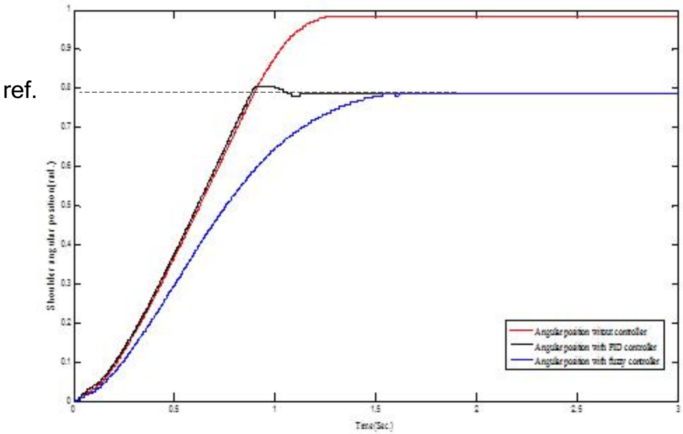

Figure 20. The response of first joint (shoulder) of IVAX SCARA Robot.

Fig.20 contains the angular position response of the joint without using controller, with using PID controller, and with using fuzzy controller.The parameters of PID controller are (K_p=0.5, K_i=0.1, K_d = 0.001), and the values of gains that are using in fuzzy controller are (g_0 = 0.3, g_1=0.1, h = 0.9).

From Fig. 20 the response of shoulder with using PID controller contains overshoot but the response with fuzzy controller not contains overshoot, but the response with using PID is faster (decrease settling time) than the response with using fuzzy controller. The characteristics of response of the first joint using closed loop with PID controller and with fuzzy controller with error criteria 2% are shown in table I. The overshoot is calculated according to:

$$\text{Overshoot } (M_p) = \frac{C(t_p) - C(\infty)}{C(\infty)} \quad (11)$$

where t_p is the peak time.

Table I. The characteristics of response of shoulder using PID and FLC.

Controller type	Rise Time (t_r) (sec)	Overshoot M_p %	Peak Time (t_p) (Sec.)	Settling Time (t_s) (Sec.)	Delay Time (t_d) (Sec.)
PID Controller	0.627	0.0266	0.9513	0.866	0.5121
Fuzzy Controller	0.9459	0	_	1.407	0.6134

The response of elbow of IVAX SCARA Robot for moving it at theta 45 degree (0.7854 radian) is shown in Fig. 21 .This figure contains the angular position response of elbow without using controller, with using PID controller, and with using fuzzy controller.

The parameters of PID controller are (K_p=0.028, K_i=0.002 , K_d = 0.001),and the values of gains that are using in fuzzy controller are (g_0 = 0.6, g_1=0.1, h = 0.978).

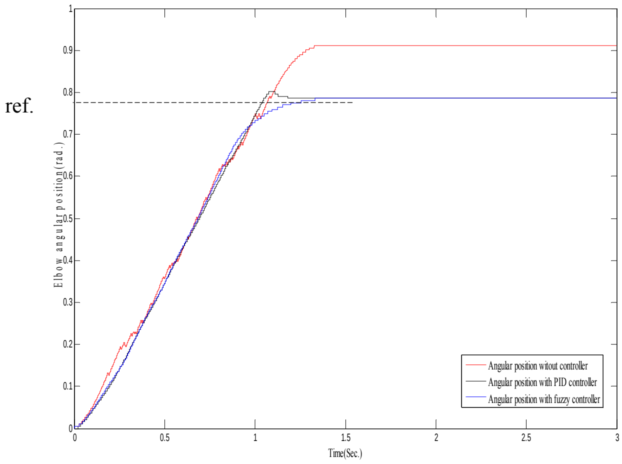

Figure 21. The response of second joint (elbow) of IVAX SCARA Robot.

From Fig.21 the response of the elbow with using PID controller contains overshoot but the response with fuzzy controller not contains overshoot, but the response with using PID is decreasing the settling time than the response with using fuzzy controller .The delay time and rise time are convergent in value for both controllers . The characteristics response of elbow using closed loop with PID controller and with fuzzy controller with error criteria 2% are shown in table II.

Table II. The characteristics of response of elbow using PID and FLC.

Controller type	Rise Time (t_r) (sec)	Overshoot M_p %	Peak Time (t_p) (Sec.)	Settling Time (t_s) (Sec.)	Delay Time (t_d) (Sec.)
PID Controller	0.7947	0.0199	1.094	1.028	0.553
Fuzzy Controller	0.7871	0	_	1.152	0.5515

The response of the fourth joint of IVAX SCARA Robot for moving it at theta 45degree (0.7854 radian) is shown in Fig. 23 .This figure contains the angular position response of wrist without using controller, with using PID controller, and with using fuzzy controller.

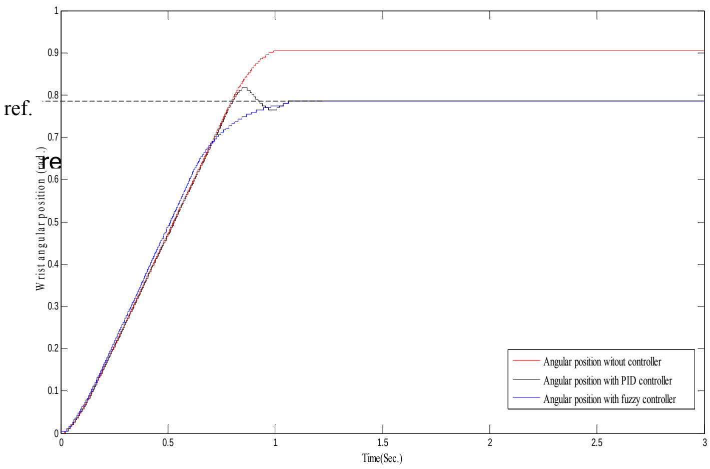

Figure 22. The response of the fourth joint (wrist) of IVAX SCARA Robot.

The parameters of PID controller are (K_p=0.0199, K_i=0.001, $K_d = 0.001$), and the values of gains that are using in Fuzzy controller are ($g_0 = 0.6$, g_1=0.1, $h = 0.978$).

From Fig. 22 the response of the wrist with using PID controller contains overshoot but the response with Fuzzy controller not contains overshoot. With using PID controller, the values of rise time and settling time and delay time are better than with using Fuzzy controller but they are convergent for both controllers. The characteristics response of wrist using closed loop with PID controller and with Fuzzy controller with error criteria 2% are shown in table III.

Table III. The characteristics of response of wrist using PID and FLC.

Controller type	Rise Time (t_r) (sec)	Overshoot M_p %	Peak Time (t_p) (Sec.)	Settling Time (t_s) (Sec.)	Delay Time (t_d) (Sec.)
PID Controller	0.611	0.0399	0.8493	o.9458	0.429
Fuzzy Controller	0.62	0	_	0.9776	0.409

The third joint (prismatic) of IVAX SCARA Robot was idle, so the prismatic distance was assumed equal 4 cm (total prismatic distance) for the computations in inverse kinematics.

VII.Conclusion

From the obtained results it can be concluded that:

1. The response of shoulder of IVAX SCARA Robot with using PID controller is fast with zero error steady state but it contains overshoot before settling at the target.The response of the shoulder of IVAX SCARA Robot with using fuzzy like PD controller is smooth with zero error steady state but it is slower than with using PID controller.With PID controller ,the rise time and settling time are less than with FLC but overshoot equal zero with FLC.
2. The response with using fuzzy like PD controller for elbow of IVAX SCARA Robot is smooth and it is fast like PID controller with zero error steady state for both controllers. With PID controller, the settling time is less than with FLC but overshoot equal zero with FLC and with FLC the rise time is better.
3. The response with using fuzzy like PD controller for wrist of IVAX SCARA Robot is smooth and it is faster than controller with zero error steady state for both controllers. With PID controller, the settling time is less than with FLC but overshoot equal zero with FLC and with PID the rise time is better.

`

References

[1] A. Huaug, M. Chien, *Adaptive Control of Robot Manipulators_ AUnified Regressor-free Approach* ,World Sciencetific Publishing Company,2010.
[2] T. Yoshikawa, *Foundations of robotics: analysis and control*, MIT Press, 1990.
[3] D.Wai, *Graphical User Interface Development for PC-Based Control of a SCARA Robotic Arm* ,Massey university,2001.
[4]Available at *http://www.anf.nildram.co.uk/beebcontrol/arms/ivax/index.html*, visited on 5/6/2012.
[5] Encoder Products Company, *Installation and Wiring Guide*, 2008.
[6] J. S. Falcon, *National Instruments, Robotics and Automation Hand book*, CRC Press LLC ,2005.
[7] K. M. Passino and S. Yurkovich, *Fuzzy Control*, Addison-Wesley Longman Inc., USA, 1998.
[8] Advantech, Data sheet, *PCI-1711/ PCI-1711L*.
[9] Advantech, *PCI-1711U Series- User Manual* ,June 2010.
[10] U. Mondal and A. Sengupta, *Real Time System Development & Speed Control of a Stepper Motor Using Commercial Soft Tools & Open Source Codes*, IJECT Vol. 2, Issue 1, March 2011.
[11] T. P. Sattar and M.Zahir, *Real Time Windows Target*, Faculty of Engineering Science and Built Environment, London South Bank University,2009.
[12] Math Works, *Real-Time Windows Target For Use with Real-Time workshop*,User's Guide,Version 2, June 2004
[13]Available *at http://www.mathworks.com/products/rtwt/description1.html* ,visited on 3/4/2013.